Co-financed by the European Regional Development Fund

Inspire Policy Making with Territorial Evidence

FINAL REPORT //

Characterization of Green Infrastructure in Latvia

ESPON GRETA Spin-off in Latvia

Final Report // June 2022

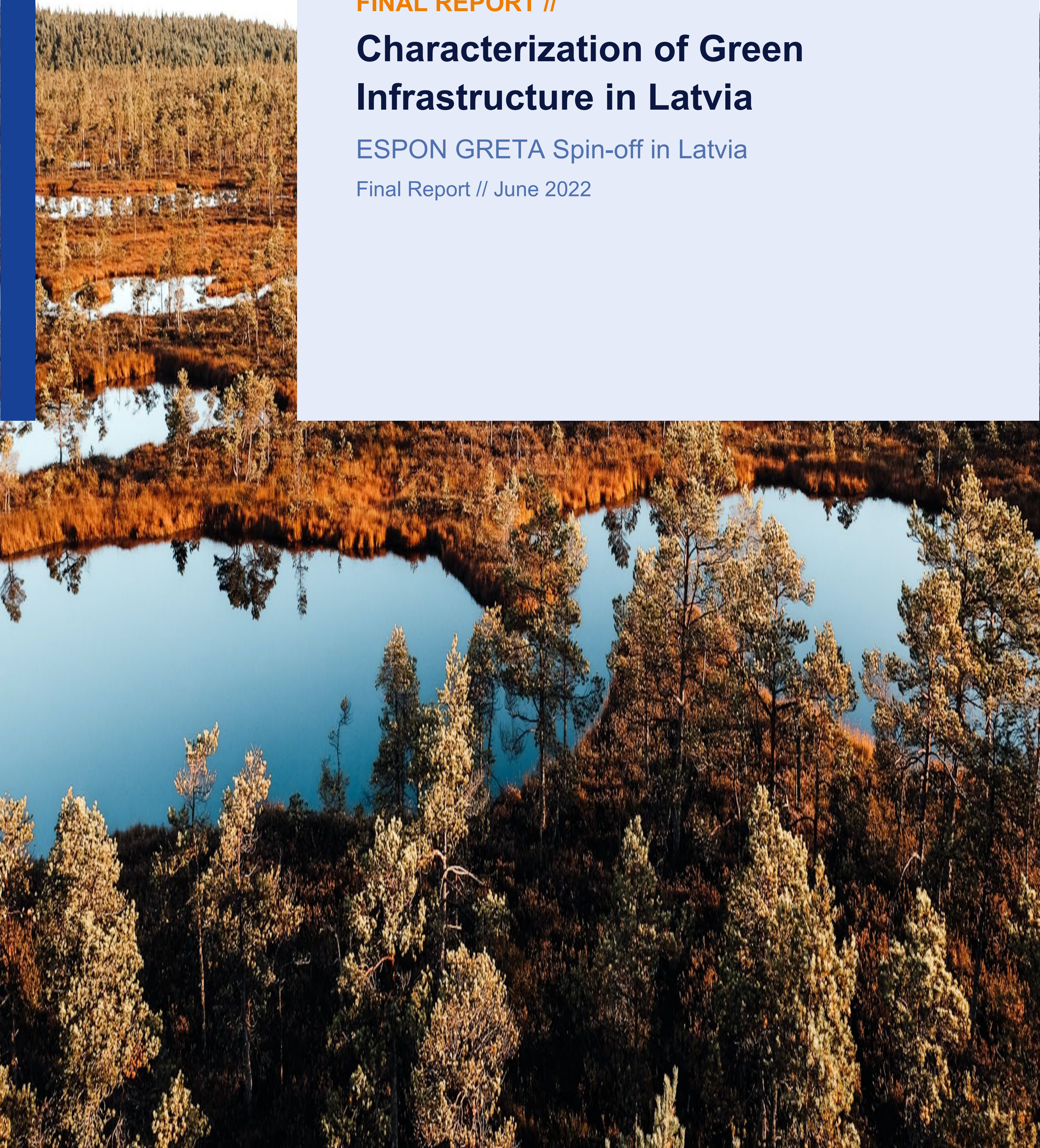

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Table of contents

List of maps, figures, charts and tables

List of maps

List of figures

List of tables

Abbreviations

CCDRR	Climate change, and disaster-risk reduction
CLC	Corine Land Cover
DRR	Disaster Risk Reduction
EAFRD	European Agricultural Fund for Rural Development
EbA	Ecosystem based Adaptation
EC	European Commission
EIA	Environmental Impact Assessments
ERDF	European Regional Development Fund
ES	Ecosystem Services
ESM	Ecosystem Services Mapping
ESPON	European Territorial Observatory Network
EU	European Union
GI	Green Infrastructure
LAU	Local Administrative Unit
LU	Land Use
LC	Land Cover
MAES	Mapping and Assessment of Ecosystems and their Services
N2K	Natura 2000 sites
NBS	Nature Based Solutions
NEP	Net Ecosystem Productivity
NUTS	Nomenclature of Territorial Units for Statistics
NWRM	Natural water retention measures
OSM	Open Street Map
PM	Physical Mapping
ROS	Recreation Opportunity Spectrum

Glossary of Terms

Term	Description
Green Infrastructure (GI)	"strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings" (EC, 2013)
Potential GI	A network of natural and semi-natural areas that is related to the spatial patterns of ecosystem services supplied by existing ecosystems and their conditions, and not in terms of areas already bound by policy measures and secured by their obligations.
Strategically planned	GI planning aims to conserve, restore, or create networks of green (and blue) areas in order to provide environmental, economic and/or social benefits for urban and rural societies (at several institutional levels). Simultaneous maximisation of all potential benefits from GI is however unlikely, thus trade-offs need to be strategically assessed. Therefore, GI networks are strategically planned in that decisions about conservation, protection, and restoration of ecosystems incorporate information on how potential geographical areas fit within a network to optimise its functioning and maximise its benefits, the connections, complementarities and contributions to different sectors. Integrating GI considerations into governance and planning processes allows all the relevant issues to be assessed and a considered comprehensive decision to be taken in order to secure as many benefits as possible. GI planning can make a significant contribution to regional development, climate change, disaster risk management, agriculture/forestry and the environment.
Network	GI relates to the identification and mapping of ecological networks. Two primary components of ecological networks are hubs and links (refer to Section 3.1). Hubs are areas of natural vegetation, other open space, or areas of known ecological value, and links are the corridors that connect the hubs to each other. A set of hubs connected by links constitutes a network that can be used to inform conservation and other related land-use decisions.
Natural and semi-natural areas	Physical features that contribute to GI are diverse, specific to each location or place, and scale dependent. Natural and semi-natural areas include elements such as: **Core areas:** e.g. local nature reserves, landscape protection areas, Natura 2000 sites. **Natural and semi-natural connectivity features***:* pastures, woodland, forest (not including intensive plantations), ponds, bogs, rivers and floodplains, wetlands, lagoons, beaches, hedgerows, small woodlands, ponds, wildlife strips, and riparian river vegetation (this list is conceptual and not all features were considered in the framework of this work – refer to Section 3.1 for further details on the features used).
Other environmental features	Other environmental features include elements such as: **Green urban and peri-urban areas:** street trees and avenues, city forests/woodlands, high-quality green public spaces and business

	parks/premises, green roofs and vertical gardens, allotments and orchards, storm ponds and sustainable urban drainage systems, and city reserves including Natura 2000 sites (this list is conceptual and not all features were considered in the framework of this work.
Ecosystem Services (ES)	The direct and indirect contributions of ecosystems to human well-being. Contributions can be of economic, social, cultural and/or ecological value. For example, a forest ecosystem might provide wood for forestry and/or for renewable energy, provide a recreational service, be part of a cultural landscape, regulate the supply of air, water and minerals, support biodiversity in the form of landscape cohesion and maintain ecosystem processes.
Other physical features	Other physical features include elements such as: Artificial connectivity features: e.g. eco-ducts, green bridges, animal tunnels (e.g. for amphibians), fish passes, road verges, ecological powerline corridor management.
Landscape scale	There is no single accepted definition of 'landscape scale'; rather, it is a term commonly used to refer to action that covers a large spatial scale, usually addressing a range of ecosystem and land uses (Ahern and Cole, 2012). In the GRETA framework, landscape scale refers to the spatial analyses performed outside the Functional Urban Areas. In the context of GRETA, landscape scale is also used as a synonym of the rural setting.
Geographical area	An area of land that can be considered as a unit for the purposes of some geographical analyses.
Trade-offs	Trade-offs describe situations that involve losing one quality of something in return for gaining another. This happens when the use of one ecosystem service directly decreases the benefits supplied by another. Trade-off situations require choices or management decisions to be made.
Synergies	Synergies describe situations where the use of one ecosystem service directly increases the benefits supplied by another service (Turkelboom et al., 2015). These are win-win situations that involve the mutual improvement of both ecosystem services.
Bundles of ecosystem services	A bundle is a set of associated ecosystem services that are supplied by or demanded from a given ecosystem or area and which usually appear together repeatedly in time and/or space (modified from Raudsepp-Hearne et al., 2010).
Multifunctionality	Multifunctionality refers to intertwining or combining different functions and thus using limited space more effectively (Ahern 2012). Multiple functions should offer benefits for humans, for instance, in relation to human health or social cohesion, and likewise secure intact ecological systems (Tzoulas et al., 2007; Lafortezza et al., 2013). The concept of multifunctionality in GI planning means that multiple ecological, social, and also economic functions shall be explicitly considered instead of being a product of chance.
Connectivity	Connectivity can be defined as the degree to which the landscape facilitates the movement or dispersal of species and other ecological flows among habitat areas. The lack or loss of connectivity reduces the capability of organisms to move and can interfere with pollination, seed dispersal, wildlife migration and breeding. In the context of GI, hostile lands would be land uses with a low or null presence of GI elements (e.g. intensive agriculture, built urban areas, transport or grey infrastructure etc.),

	which constitute main obstacles to the inter-linking of high quality 'green spaces' of natural/semi-natural lands (Estreguil et al., 2016)
Islands	Hub areas that due to their physical configuration in the landscape resemble islands like features for species and habitats.

1 Introduction

The main objective of the project is to undertake **in depth analysis and characterization of green infrastructure (GI) in Latvia** from a multiscale perspective, and to outline **policy recommendations** that could build the basis for comprehensively embedding the concept of **GI into legislation and formal planning processes**.

Several Latvian municipalities are working on implementing the GI concept into their local government spatial plans, and to competently guide this initiative and any future ventures the Ministry of Environmental Protection and Regional Development of Latvia, as the authority responsible for overseeing planning, needs in-depth knowledge and analysis on GI. Ultimately, the Ministry hopes to comprehensively embed the concept of GI into legislation and formal planning processes and to go beyond just municipal initiative. In the future an initiative is considered to potentially address this via GI planning guidelines for municipalities.

Operationally, the project was organised into two distinct phases. The first phase provided the initial mapping backbone for GI and Ecosystem Services (ES) in Latvia with a focus on recreation and flood regulation and the second aimed at providing policy recommendations to further support the GI concept in active policy making.
The present report covers the mapping backbone activities.

The development of the spatial analysis in Latvia is aligned with the **methodological approach developed in the ESPON GRETA project** *"Green infrastructure: Enhancing biodiversity and ecosystem services for territorial development"*[1] which is described in the Terms of References and has been **tailored to the Latvian reality and the data available.**

A number of **interactions and agreements with local stakeholders** (i.e., bilateral online meetings, email exchange) allowed the **customization of the methodology** to better respond to their priority needs, interests and policy objectives to be addressed and considering the feasibility of the analysis within the timeframe and resources available.

[1] See ESPON GRETA: https://www.espon.eu/green-infrastructure

2 Overview of the methodological approach

The methodological approach for delivering the study follows a four-step interactive process.

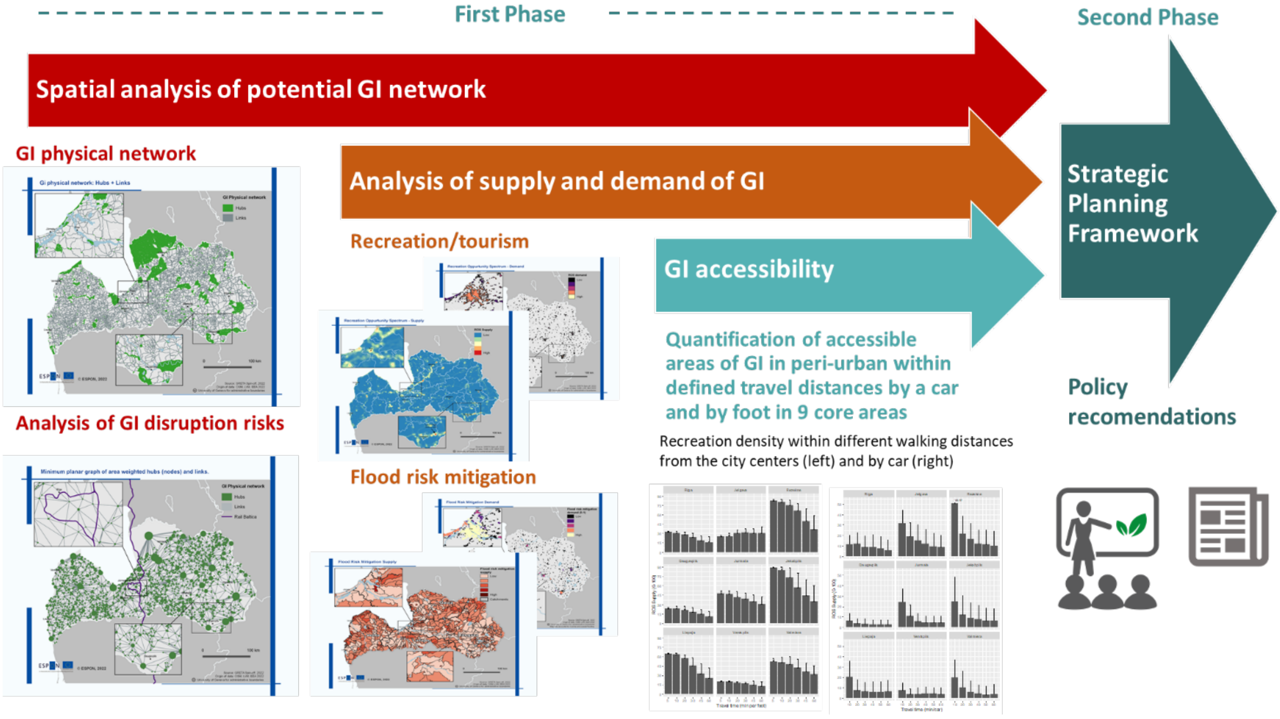


Figure 1 Methodological approach for in-depth characterization of Green Infrastructure in Latvia. Own elaboration. 2022.

The initial phase of mapping backbone for GI and ES in Latvia features a range of specific subtasks that are described in greater detail below. This phase includes the mapping of the GI physical network which shows the connectivity of GI elements as well as an analysis of supply and demand of GI. Thereby the physical network is a component of the potential GI which can be provided by the entirety of green and blue elements across Latvia.

2.1 Spatial analysis of potential GI network in Latvia

As stated above, the delivery of the spatial analysis of potential GI network in Latvia is split into two main subtasks:

a. Mapping the potential GI network at the national scale.

The spatial distribution of the physical GI network in Latvia has been mapped according to the ESPON GRETA approach for **Physical Mapping. (PM)** and **Ecosystem Service Mapping (ESM)**.

The methodological approach aims at integrating the two key underlying principles of a GI network, as defined by the European Commission and similarly stressed by academic literature – *connectivity* and *multifunctionality*.

Connectivity refers to the enhancement of species' ability to move between areas, and can be of a structural nature (i.e. habitat continuity) or functional nature (i.e. how landscapes allow various species to move and expand to new areas without necessarily being physically connected). *Multifunctionality,* on the other hand, represents the ability of the GI elements (i.e. hubs and links) to simultaneously provide multiple ES and other benefits in the same spatial area (Mell, 2017).

The ESPON GRETA approach has been customized to better fit with the Latvian reality and data available, as it has been the case in particular for the delineation of the hubs.

For the purpose of the GRETA Spin-off the priority, as agreed with local stakeholders, has been placed on the evaluation of two ES: Flood risk mitigation and recreation.

b. Analysis and mapping of GI network disruption risks

This subtask consists of mapping and evaluating the GI network disruption risks. Considering the resulting maps from above mentioned subtasks, an analysis of the GI network disruptions risks has been undertaken. The analysis mainly focuses on the ones posed by Rail Baltica. In the second phase of the project, the analysis would allow to investigate how these risks could be compensated by strengthening the GI network elsewhere.

2.2 Analysis of supply and demand of GI

Once the potential GI network in Latvia is elaborated the second step was to map and assess the balance between the demand and supply for two priority ES provided by the GI: flood risk mitigation and recreation.

The balance between the demand and supply of flood regulation entailed the analysis of flood risk maps as input for the analysis of demand and cross analysis with the GI network multifunctionality (see sections 3.3.1 / 4.2.1 for further information).

The balance between the demand and supply of recreation provided by GI at a national scale entailed the analysis of population density data and distances to GI network, as input for the analysis of demand for recreation and cross analysis with the GI network multifunctionality (see section 3.4/ 4.3 for further information)

2.3 GI accessibility assessment

In a third step an assessment and quantification of accessible areas of GI in peri-urban areas (9 core areas) within defined travel distances by a car and by foot, from an urban centre was undertaken. The GI maps elaborated in Tasks 1.a. have been used for the purpose of the analysis. The outcome of the analysis aims at getting a better understanding of the urban population for whom the GI is accessible and provide insights in any inequalities related to GI accessibility between cities.

2.4 Elaboration of the Strategic Planning Framework

In the final step, based on the in-depth analysis and characterization of GI in Latvia, policy guidelines and recommendations are outlined as a basis for comprehensively embedding the concept of GI into legislation and formal planning.

The policy recommendations are drawn based on the points crystalised during mapping and analysis in Tasks 1, 2 and 3, with a particular focus on the enhancement of Nature Based Solutions, and this will entitle a discussion with the Ministry of Environmental Protection and Regional Development of Latvia, to enhance mutual understanding and facilitate development of the recommendations.

Based on the findings obtained from the mapping phase an **online workshop meeting** with the Ministry of Environmental Protection and Regional Development of Latvia was conducted to enhance mutual understanding and facilitate development of the recommendations:

a) Contrast and validate proposal for tentative spatial planning framework and preliminary guidelines

b) Discuss around disruption risks, recreation demand and the consideration of climate change scenarios for flash floods in flood risk mitigation in future studies

c) Discuss on the implementation: barriers/ constraints, opportunities, and mechanisms for embedding GI into planning.

3 Data processing

The application of the GRETA methodology at national level required an adaptation of the workflow to be able to integrate higher resolution in-situ data. A detailed description of the processing steps applied thresholds and input data are provided further below. The processing is split by target GI component (Hubs, Links, Ecosystem services). The end products of the workflow are provided within the delivered geodatabase. Intermediate steps are not provided. All processing was conducted in R (R Development Core Team, 2021) and QGIS (QGIS Development Team, 2020).

3.1 Input data

A total of 17 different layers were utilized to produce the GI physical network as well as Ecosystem Services (Table 1). A larger amount of data was scoped in an initial data collection phase, however, not all thematic data was accessible and available in a suitable geoprocessing format.

Table 1 Selected input data sets to produce physical GI network and Ecosystem Services.

GI Com-po-nent	Type	Name (EN)	Name (LV)	Description	Source
Phy-sical GI	Hubs	CDDA	CDDA	Natura 2000 and national protected areas	CDDA
		Protected areas / Bi-otopes	Mikrolie-gumi	Microreserves + Buffer zones	ttps://data.gov.lv/dati/eng/dataset/mikroliegumi
		National topogra-phic map	To-pogrāfiskie dati	Topographic map	https://lvmgeo.lvm.lv
Eco-sys-tem Ser-vices	Out-door recre-ation	Recreatio-nal forests	LVM e-komeži rekreācijai		https://lvmgeo.lvm.lv/PublicData/SHP/LVM_E-KOMEZI.zip
		Hiking trails (nati-onal data)	LVM dabas takas		https://lvmgeo.lvm.lv/PublicData/SHP/LVM_DA-BAS_TAKAS.zip
		Hiking trails (OSM)		route = hiking	https://wiki.openstreetmap.org/wiki/API
		Tourism infrastruc-ture	LVM tūrisma inf-rastruktūra	Viewpoints, Picnic areas 6 = 13	https://lvmgeo.lvm.lv/PublicData/SHP/LVM_TU-RISMA_INFRASTRUKTURA.zip"
		Picnic areas	LVM tūrisma atpūtas vie-tas		https://lvmgeo.lvm.lv/PublicData/SHP/LVM_TU-RISMA_ATPUTAS_VIETAS.zip
		Bicycle trails		route = bicycle	https://wiki.openstreetmap.org/wiki/API
		Licenced fishing wa-ters	Licencētās makšķerēš anas ūden-stilpes	Licenced fishing waters (payment required). Does not include all fishing wa-ters per se.	https://www.epakalpojumi.lv/odata/service/BodyOf-Waters
		Bathing water qual-ity monitor-ing sites	Bathing water qua-lity	Bathing areas with valid monitoring programme.	https://www.vi.gov.lv/en/bathing-water-quality
	Flood risk	River Flood Ha-zard Map	Upes plūdi		https://videscentrs.lvgmc.lv/iebuvets/pludu-riska-un-pludu-draudu-kartes

	miti-ga-tion	Coastal Flood Hazard Map	Piekrastes plūdi		https://videscentrs.lvgmc.lv/iebuvets/pludu-riska-un-pludu-draudu-kartes
		River Basins	Dalbaseini	Subcatchment extents for the 4 larger drainage Basins	https://data.gov.lv/dati/eng/dataset/upju-sateces-baseini-inspire-wms76
	Other	Administrative units 2021	Administratīvās teritorijas - 2021		https://data.gov.lv/dati/dataset/7bb04db9-97ce-4a30-b93a-10ba8dafd104/resource/eaf5594f-cec9-4cc2-819a-5cdc14004bc2/download/administrativas_teritorijas_2021.zip
		Delineation of urban centres	Adrešu reģistra telpiskie dati	2 pilsetas and 7 valstpilsetas	https://data.gov.lv/dati/eng/dataset/valsts-adresu-registra-informacijas-sistemas-atvertie-dati/resource/f539e8df-d4e4-4fc1-9f94-d25b662a4c38
		Densely populated areas	Blīvi apdzīvotas teritorijas		https://data.gov.lv/dati/dataset/2c07c211-0d78-49d3-9500-20b6f54f2a63/resource/93c8a5ed-0930-45f1-afeb-1105b6d5a7ca/download/dpa_2019_public.zip
		OSM natural water		natural = water	https://wiki.openstreetmap.org/wiki/API
		Rail Baltica		Name = Rail Baltica	https://wiki.openstreetmap.org/wiki/API

3.2 GI physical network

3.2.1 Hubs & Links

The hubs and links are generated from the topographic map and protected areas (Figure 2). Hubs are protected areas in the landscape. Hubs feature a large size variety and different hub sites may also feature a mixed legislative state. For example, a given area might fall under Natura2000, National Nature Protection Law or both. Thus, some sites can also include agricultural or non-urban areas, albeit to a different degree. A notable example for an extremely large Natura2000 site is the Northern Vidzeme Biosphere Reserve, which covers approx. 7% of the entire country (~445700 ha).

Marine areas are excluded given the focus on connectivity of terrestrial animals and terrestrial animal dispersed plants. The limits for the analysis are thus the administrative boundaries of Latvia. The mapping of the physical network was guided by the previously elaborated GRETA methodology; however, the full methodology could not simply be translated to national level as it was designed for a different spatial scale as well as base data. The current approach is independent of size thresholds for patches as well as set minimum distances between patches due to the higher resolution data and larger scale of analysis.

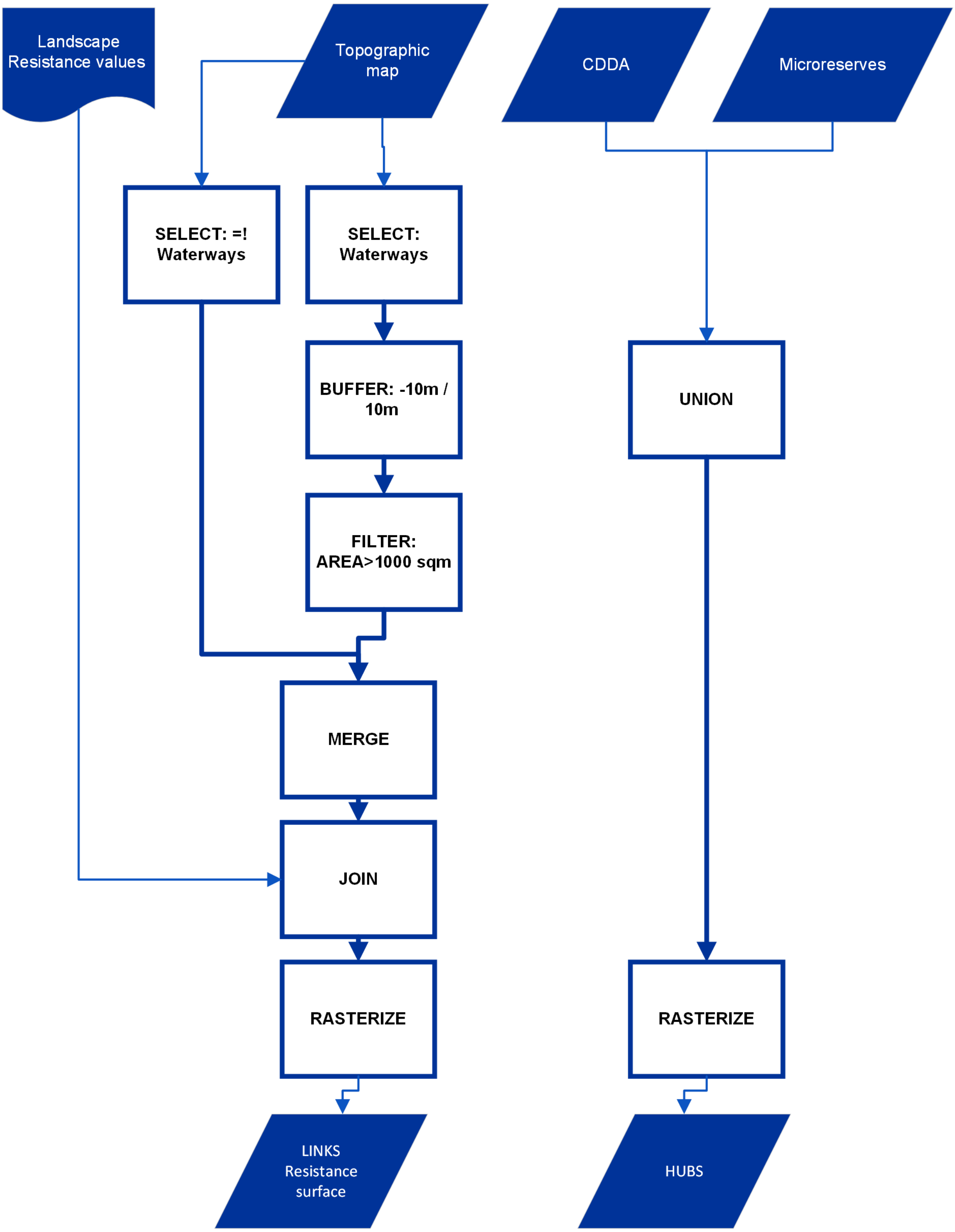


Figure 2 Schematic workflow for creating GI physical network on the basis of national topographic map and protected areas.

Links are predominantly natural and semi-natural areas that connect the hubs. These connectors present movement corridors across the landscape and thus are of mixed landuse. Links were identified using the function 'MPG' from the R package 'grainscape' (Chubaty, Galpern and Doctolero, 2020). This algorithm utilizes a minimum planar graph with a least-cost-distance (LCD) method that identifies the shortest paths between the perimeters of hubs across the landscape (Fall *et al.*, 2007). Figure 3 shows the general process of producing the physical network with the minimum planar graph.

Thereby, distance is not the only criteria to be considered but also the difficulty that a species encounters while moving between different habitats. Movement between habitats might be risky due artificial constructions such as roads or highways, but also rivers or smaller creeks may present barriers. There might be a lower availability of food resources, challenging topography, or a higher risk from predators in areas between hubs.

The degree of difficulty that the landscape poses to the free movement of animals is commonly referred to as landscape resistance. A resistance landscape can be easily produced from existing land cover maps by reassigning classes with new values which are based on their presumed resistance. The main question here is how to define these values. The reassignment of values is most commonly conducted along an interval scaled gradient, ranging from the minimum resistance, which resembles suitable habitat to a maximum resistance, indicating unsuitable, potentially deadly, areas. The absolute value range is thereby mostly guided by file format considerations. The attribution of values to land cover classes between the minimum and maximum boundaries is heavily dependent on the evaluation and selection of the researcher and presents an extensive topic (Zeller, McGarigal and Whiteley, 2012). In the current attribution, forests present the least resistance to movement, while urban areas and larger rivers as well as highways present barriers and are thus likely to be avoided. Classes in between have been assigned by their structural proximity to forests. Please refer to the annex for look-up tables showing the full conversion chart for the classes within the Latvian topographic map into resistance values.

Performing a sensitivity analysis regarding their assignment is generally recommended. However, in the present case an accurate description of connectivity parameters is not essential to facilitate an overview of a physical GI network at national level. In addition, the network is not directed at a specific species dispersal capacity and oriented towards landscape level analysis.

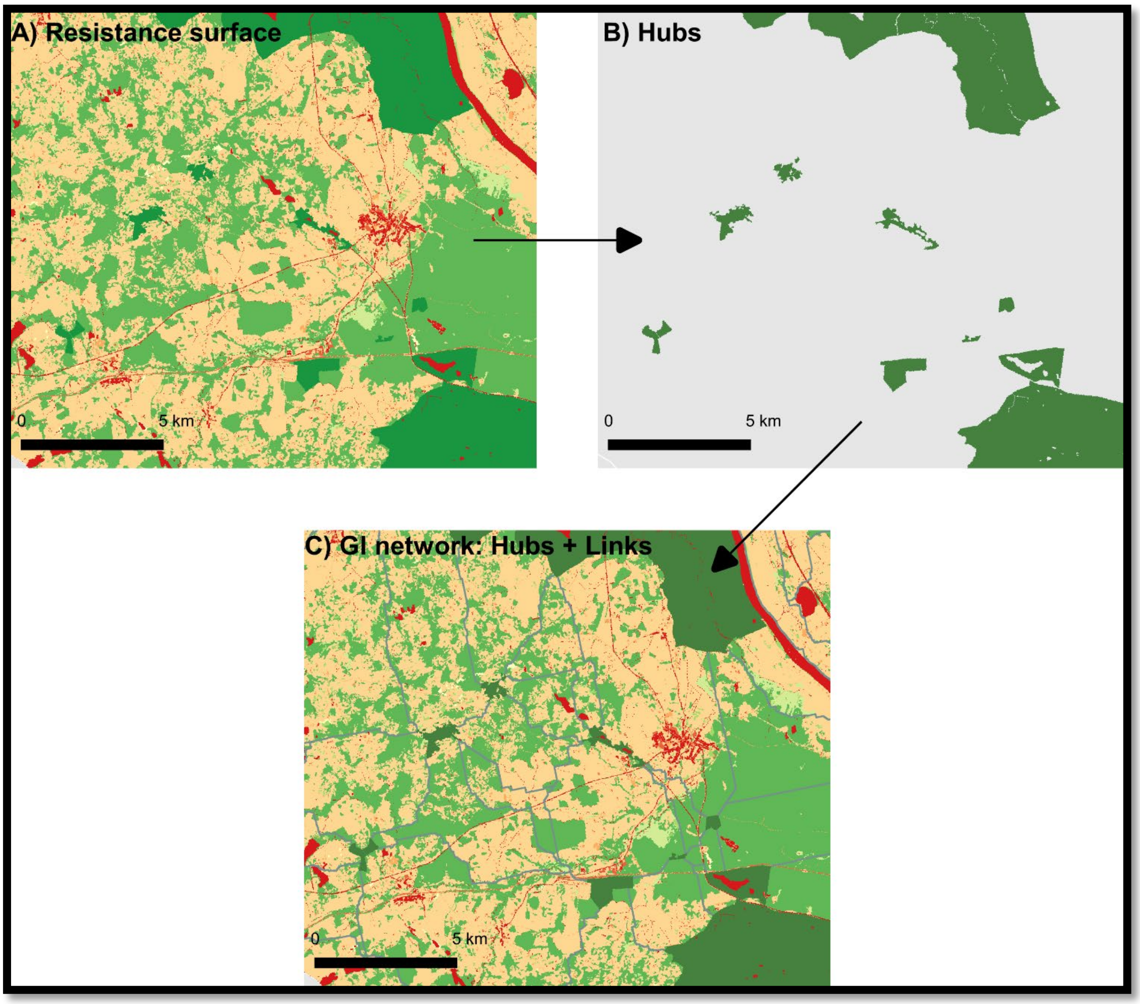
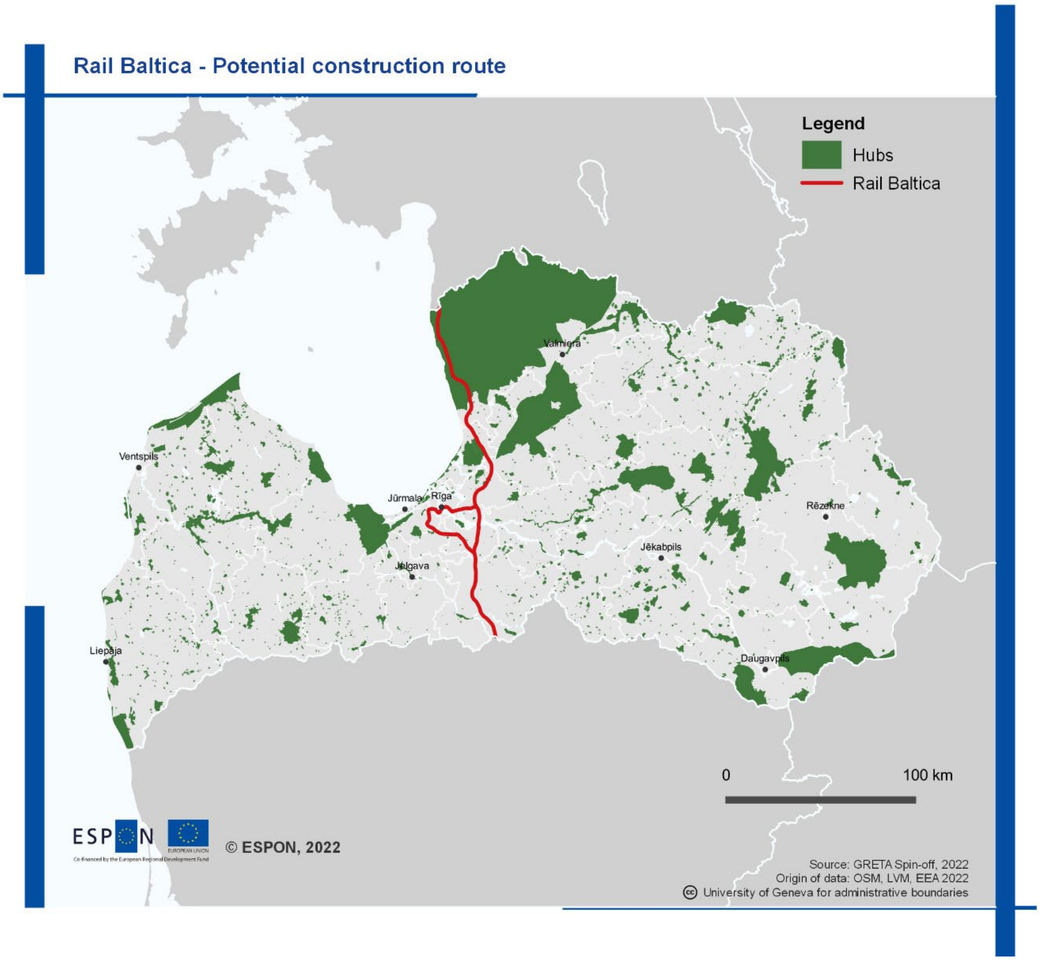


Figure 3 Process of deriving a minimum planar graph representing the GI physical network in the vicinity of Ilūkste, using resistance surface (A) and hubs (B).

3.2.2 GI network disruption risk

The GI physical network was analysed with regard to major alterations of landscape connectivity to be expected by the construction of the "Rail Baltica" high-speed railway line. This railway crosses the complete country from Grenctāle in the central South over Riga to Ainaži at the northernmost Coastal border. The final route of the railway is currently (Status April 2022) still under active environmental impact assessment and the construction of the railway has only begun. All potential variants of the planned route were extracted from OSM (using the tag name = Rail Baltica). This preliminary railway was compared and aligned with the interactive map provided by the Rail Baltica construction consortium (https://info.rail-baltica.org/en/infrastructure). This railway presents a major barrier to animal movement and to decrease its negative impacts on animal dispersal specific connectivity measures, such as green bridges and underpasses, are foreseen.

However, the specific location of these measures has not yet been finalised. This presents a problem for a connectivity analysis as the railway essentially divides the country into two segregated landscapes (Map 1). In order to account for a small degree of movement across the railway, the network was treated as interrupted in any case where river crossings require the construction of bridges. According to the environmental impact assessment (EIA) for the railway[2], areas below bridges are to be designed to allow animal passage. The circumstance that the only gaps that can be accounted for are waterways means that true disruption risk towards the GI physical network is likely overestimated. Nonetheless, this approach allows to identify critical areas of network disruption.



Map 1 Potential construction route of the Rail Baltica high speed railway.

The final disruption risk was analyzed by adding the Rail Baltica into the resistance surface and comparing the physical network before and after inclusion of the railway. Thereby the Rail Baltica was assigned with a resistance value of 500000. This value has been based on the existing resistance surface (see chapter 3.2.1) and reflects the maximum of horizontal resistance encountered within the country.

[2] The full EIA documentation package can be retrieved from https://makonis.edzl.lv/d/da5579a9e4/ - last accessed 24/04/2022

3.3 Ecosystem services

The two selected ecosystem services that indicate the functions of the landscape are flood risk mitigation and recreation potential. Both services are split thematically representing demand and supply for the given service.

Demand describes the direct need for an ecosystem service whereas supply resembles the total ‘quantity’ or degree of a service at a specific location.

3.3.1 Flood risk mitigation

Flood risk mitigation is a vital ecosystem service especially in view of the potential increase of severe weather events that have been associated with the intensification of climate change. In Latvia more than 90% of the run-off is carried by five largest Rivers (Daugava, Lielupe, Gauja, Venta, Salaca).

While overall run-off has been predicted to decrease in the future decades, spring floods are likely to continue to be a threat. In addition to physical flood protection measures, finding natural solutions for flood mitigation remains essential to reduce hazardous flooding.

3.3.1.1 Supply

Natural flood protection is provided by a range of environmental compartments and components. Wetlands and vegetation intercept precipitation and buffer peak run-off events. Soil- and hydrogeological properties are an important predictor for the discharge characteristics of a catchment. Likewise, the physical structure and topography within a watershed also influence the vulnerability towards flooding.

Unlike land use induced changes involving deforestation, drainage or channelisation, natural soil hydrogeological and topographic properties in the wider catchment area can only be altered to a limited degree by human intervention. Because there is such a direct link between land use (and land cover) within a catchment and its discharge properties it has been the research target of numerous comparative hydrological modelling assessments in the past.

This also provides a strong basis for it to be used as proxy for flood protection by natural elements. Clearly, this can only be indicative as it does not account for interactions between the environmental compartments or includes discharge dynamics information.

In order to map flood risk mitigation, supply the land use categories of the Latvian topographic map were reclassified into natural, agricultural and artificial classes. Subsequently, their flood mitigation potential was classified into three classes (“low”, “medium”, “high”) based on their degree

Subsequently, the reclassified topographic map was intersected with the national river basin catchment data in order to summarise the land use within each contributing river. Lastly, the class proportion of each land use class used to weight the individual flood risk mitigation strength by natural classes.

3.3.1.2 Demand

The basic input data to generate the flood risk mitigation ES are the flood risk maps provided by the Latvian Environmental, Geology and Meteorological Centre LVGMC. These flood risk maps show interpolated coastal and riverine flooding heights for 10/100/200 year return periods (Figure 4).

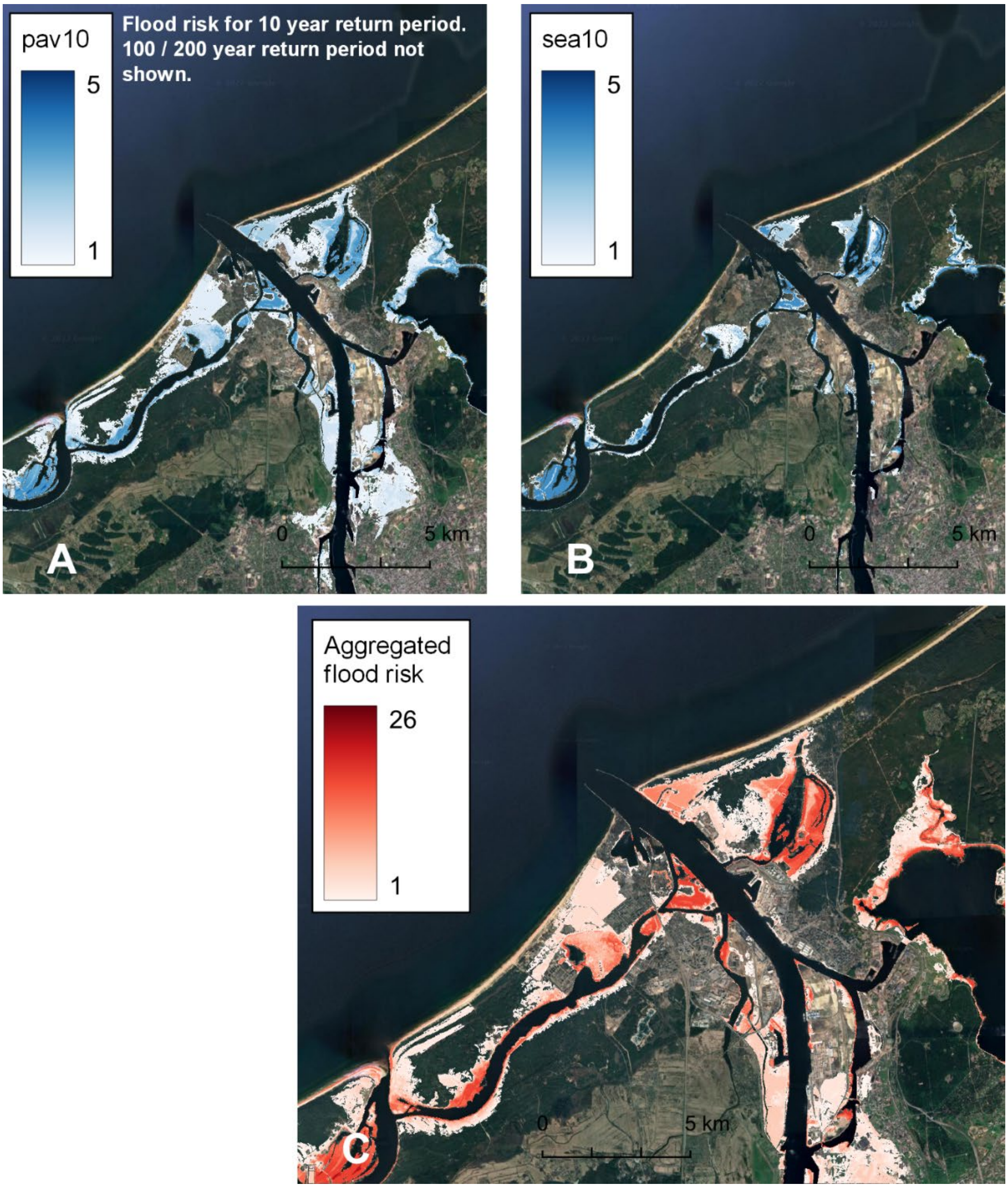


Figure 4 Example of input data provided by LVGMC. Example shows flooding extent and height(m) for riverine (A) and coastal flooding (B) within Riga for 10 year return period. C indicates the summed flooding extent layers (n = 6).

This flood risk data was summed across the periods to obtain a (dimensionless) flood intensity layer.

Flood risk demand was then derived by intersecting this intensity layer with the population density layer which provided population estimates within urban (built-up) areas.

More specifically, flood risk mitigation demand is calculated by first establishing the proportion of flooded area and multiplying this value by the population recorded for a given polygon and the median flooding intensity (Equation 1). Finally, the value is rescaled to a 0-1 value range (Equation 2).

$$fr_{affected} = \frac{Area_{flooded}}{Area_{polygon}} \times Population_{polygon} \times Flood\ intensity_{Median} \quad (1)$$

$$fr_{demand} = \frac{(fr_{affected} - \min(fr_{affected}))}{(\max(xfr_{affected}) - \min(fr_{affected}))} \quad (2)$$

3.3.2 Recreation opportunity spectrum

Access and availability of recreation opportunities in natural areas is fundamental to human well-being. With a large number of lakes and rivers, an extensive coastline and numerous wetlands Latvia boasts a large range of possibilities for leisure activities in natural environments.

Recreation provided by green infrastructure does not only have an intrinsic value but provides a wide base for touristic and associated businesses and downstream providers. Especially for rural communities income generated from natural recreation opportunities can provide an important lifeline.

Because recreational ecosystem services cover a large range of activities it is hereinafter referred to as the recreation opportunity spectrum (ROS).

3.3.2.1 Supply

ROS supply was mapped on the basis of national and OSM data. The data includes point, lines and polygon data and covers essential and widespread recreational activities such as hiking, biking, swimming, fishing and environmental education (c.f. Table 1).

Whereas the gathered information is sufficient for simple visual mapping purposes, it cannot directly be merged into a single layer due to file-format restrictions. Combining the data into a single layer, however, allows for improved downstream applications and analysis. In general, there were two options to combine the data, either a simple rasterization process (i.e. converting the data to a raster grid format of uniform resolution) or generating a density-based metric. In case of the former option, the different data elements are likely to underestimate the importance of line and point features. Therefore, a dedicated density-based approach was developed. The final layer indicates the dimensionless interpolated density of recreation opportunities from each location within a 1500m radius. This radius was chosen to highlight the availability of leisure activities within immediate walking distance. The description of the detailed workflow can be found below (Figure 5).

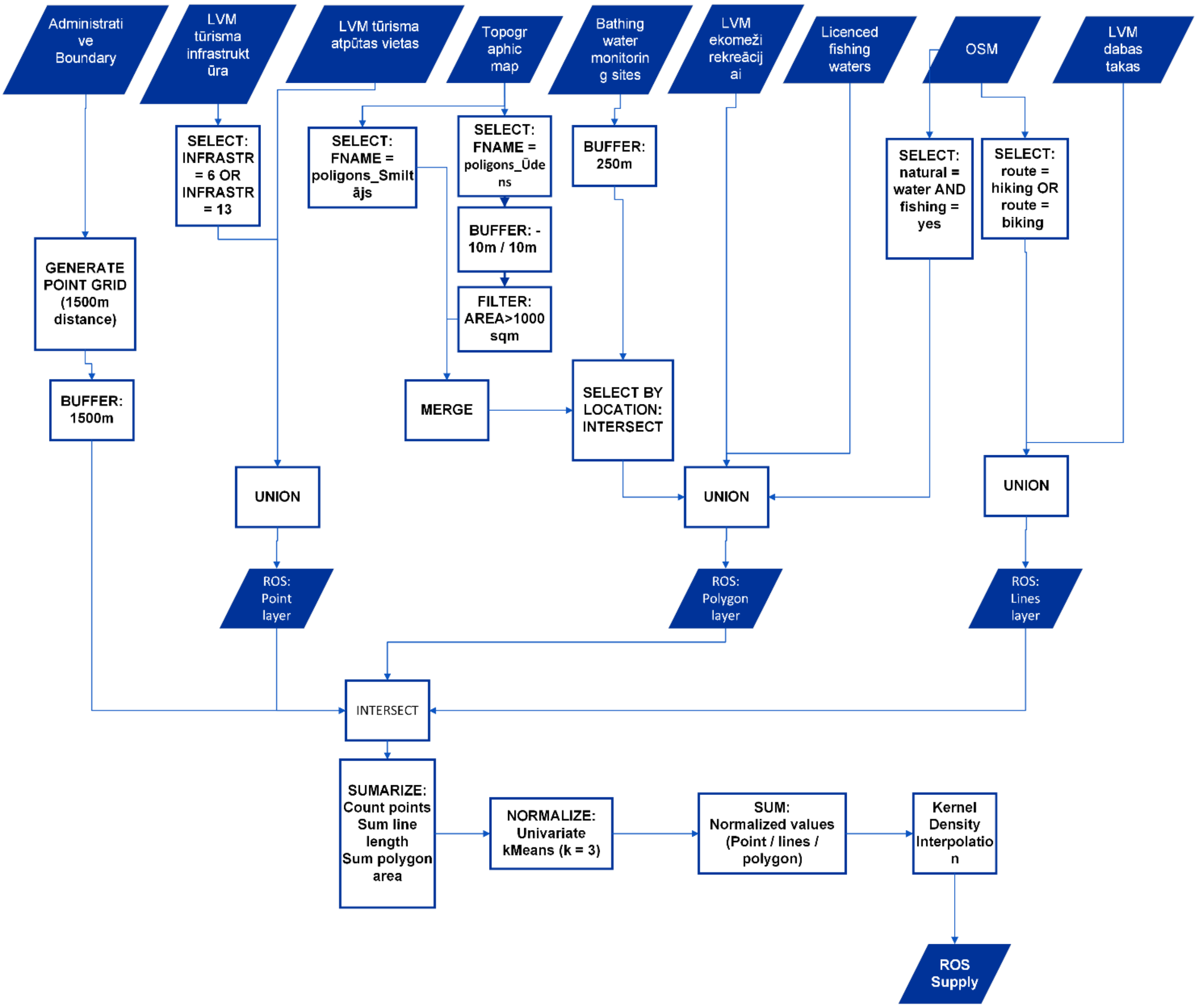


Figure 5 Workflow for producing ROS supply layer from input data.

3.3.2.2 Demand

While there is a wide range of input data to map the supply of leisure activities, data on the demand of specific recreation activities is generally scarce. Visitation frequency data is usually restricted to single sites or specific activities and rarely covers regional or even national scale. On the other hand, common touristic variables, such as nights spent in accommodation are usually published at regional level and therefore cannot always be precisely linked to location or type of touristic green infrastructure.

While there is additional information on recreation demand available it could not be obtained prior to writing this report due to administrative reasons. This information contains a point layer indicating the location, type and visitation frequency category for touristic attractions and businesses. In absence of the required baseline data or mapping initiatives, proximity-based approaches offer a solution of bringing together supply and demand by highlighting recreation opportunities available to the population.

Recreation demand was therefore mapped by intersecting the population density layer (Blīvi apdzīvotas teritorijas), which indicates population within built-up areas, with the ROS supply layer. ROS Demand was then calculated by essentially dividing the summed ROS supply by the total residential population. (Equation 3).

$$ROS_{Demand} = \frac{\sum_{i=1}^{n}(ROS_{Supply})}{Population_{Residential}} \quad (3)$$

The final result is then classified into 5 classes ranging from very low – very high demand using Jenks univariate k-means clustering (Jenks, 1967).

3.4 Green Infrastructure accessibility assessment

Green infrastructure in urban and peri-urban areas serves to provide a large variety of ecological and recreational functions (Poelman, 2018; Vargas-Hernández and Zdunek-Wielgołaska, 2021). There is an overwhelming base of evidence supporting the finding that the availability of urban green (and blue) spaces to inhabitants of cities plays a major role in enhancing a citizens quality of life and well-being (Jeanjean, Monks and Leigh, 2016; Frumkin *et al.*, 2017; Houlden, Jani and Hong, 2021).

The densification and expansion of urban areas, can result in the loss of urban green spaces and subsequently decreases in human well-being and health, amongst other societal repercussions (Regional Public Health, 2010).

Because the link between well-being and access to urban green and blue space is well documented, the accessibility assessment utilised the ES 'supply of recreational opportunities' to assess accessibility. Rather than using urban green and blue spaces directly, using the ES has the advantage of integrating the direct use of GI towards the citizen.

Accessibility of green infrastructure was assessed utilising the ORStools QGIS plugin (https://github.com/GIScience/orstools-qgis-plugin.git). The plugin contains a set of tools to generate isochrones using the openrouteservice (ORS) API. Isochrones were calculated in 10-minute increments starting from the respective city centre of the nine urban cores. Both walking and car travel time were assessed. Walking time increments were slightly adapted with regard to their increments (5, 10, 20 30 45, 60) to account for closeness. An example of the isochrone surfaces is provided in Figure 6.

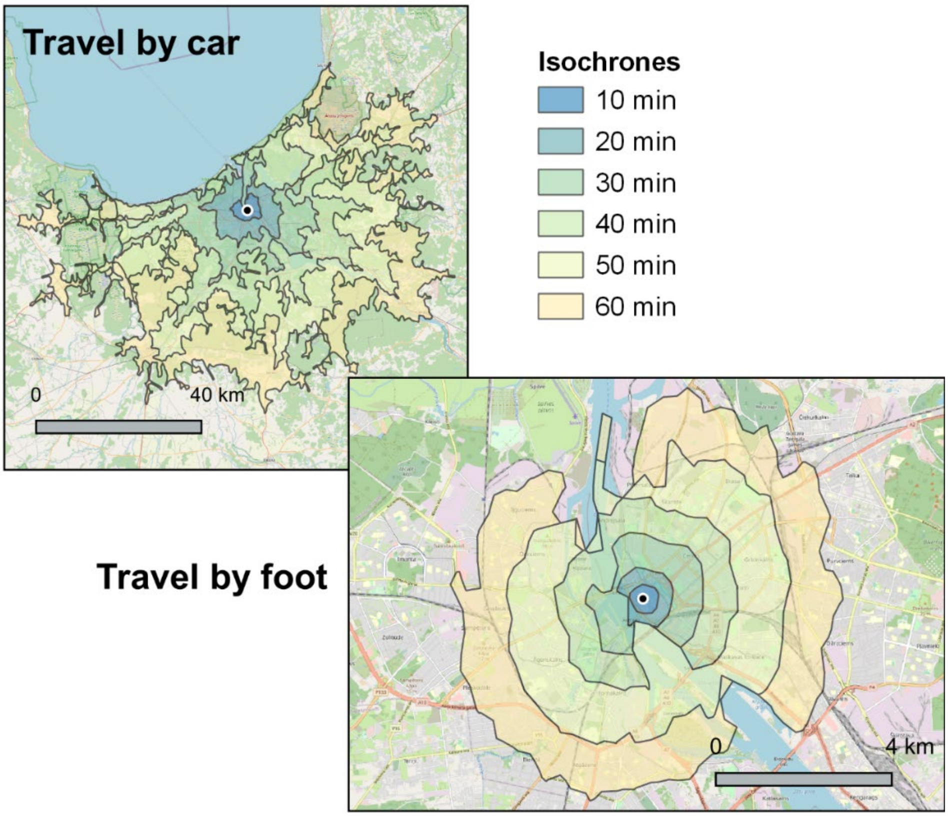


Figure 6 Example of travel isochrone surfaces generated for the city of Riga with ORStools toolkit. Background: OSM

4 Results

The following chapter shows the results of the GRETA methodology application to Latvia. It includes information on the location of the physical GI network, showing were hubs are located and how they are connected by (predominantly) natural and semi-natural links. Furthermore, the potential disruption of the network by the Rail Baltica project is analysed.

Demand and supply for both flood risk mitigation and are mapped. The accessibility of GI in urban areas is explored utilising the available recreation opportunities for residents by travel isochrones.

Where possible the maps provide specific physical units. However, in many cases this standard mapping practice was not feasible or would act rather convoluting than adding additional benefit to the user. This is mainly due to the circumstance that the ecosystem services considered in the present case either present a mixture of different data dimensions (c.f. points, lines and polygons) or are the result of a multi-step production methodology. If specific values are of interest these may be retrieved from the accompanying data package.

4.1 GI physical network

This section provides the results for the GI physical network and its disruption risks.

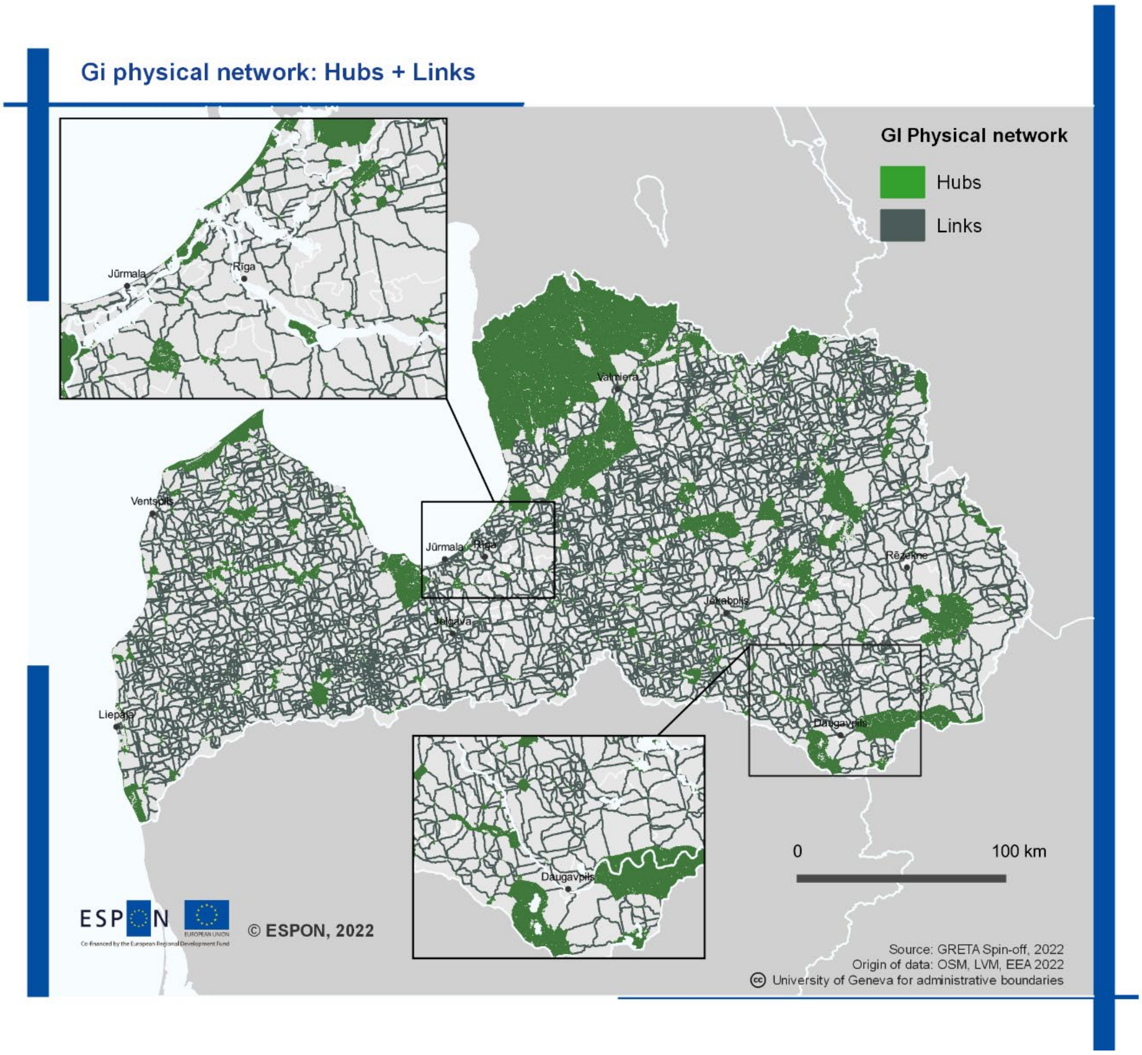
4.1.1 Hubs & Links

The identified physical network contains a total of 34496 individual hubs and a total of 6886 link segments (Map 2). On average a hub is around 489 ha (Std. Dev = 9346). Hubs vary extremely in size and may range from as little as 1 ha to 445700 ha. Hubs below a minimum size of 1ha were discarded in order to avoid convoluting the derived link network. Complex hub shapes provide more opportunities for dispersal between hubs. In Latvia, the majority of hubs appear to be rather uniform in shape and feature a lower perimeter-to-area-ratio (Mean = 0.97 / SD = 0.16).

Links essentially present the least-cost-distance path for movement between hubs. As such, they can also intersect and branch out to different hubs. Therefore, their length can also vary substantially. As the links are line features, they indicate a directional path rather than a surface extent. Much of the crossed habitat could be actively and /or regularly utilised by animals. Much of Latvia is connected by the small scale protected areas ("Mikroliegumi") which serve as stepping stones between larger coherent patches of protected area, but also enhance the connectivity by acting as a multiplier on the density and availability of movement corridors.

At national level a lower degree of connectivity can be observed mostly in the central and eastern regions which feature higher proportions of agricultural use. Although these areas are likely more isolated in comparison to other regions it is important to state that they do not appear to be isolated due to the circumstance that agricultural areas are also considered to be utilised as links. It is important to consider that the current representation of the GI network shows the complete network as such and has not been thresholded to show how the network is perceived for animals with varying dispersal capacity (i.e. ability to overcome resistance).

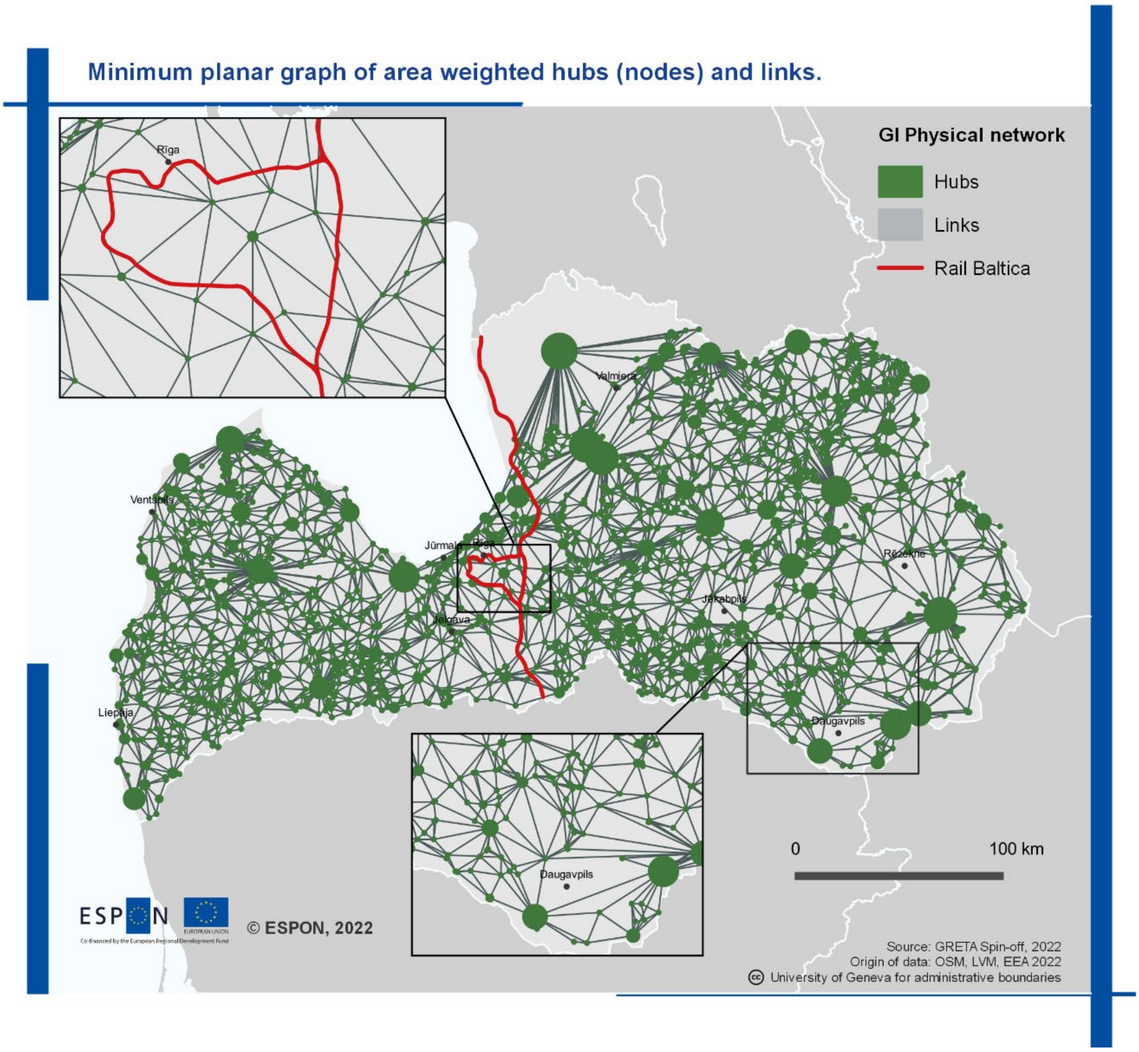
This is mainly due to the circumstance that the GI network is kept at a generic level and should indicate hot- and cold spots at national level.



Map 2 Realisation of a minimum planar graph representing physical GI network in Latvia. Green areas correspond to hubs (protected areas) and dark grey are links connecting the hubs via predominantly natural and semi-natural areas. Links present potential movement corridors for terrestrial wildlife and are calculated on the basis of a least-cost-path distance approach.

4.1.2 GI network disruption risks

Map 3 shows the GI network, representing the patches by area weight. The planned construction pathway of the Rail Baltica has been superimposed to show which hubs and links might be affected by the construction. It includes the full network of the planned and existing railway path. In total, the railway interrupts potential links at 52 different locations. This translates into an average link interruption for every 11km of railway section. Due to legal restrictions, the railway avoids most (protected) hubs. More than 120 different hubs are potentially affected by the network disruption due to interruption of links amounting to almost 40% of the total hub area. This large proportion is related to the fact that the railway crosses the major Vidzeme biosphere reserve as well as brushes past two larger national parks (Gauja national park, Dzelves-Kroņa purvs).



Map 3 Area weighted representation of hubs (nodes) and links. The plotted size of the node symbol has been scaled to the area of the respective patch.

Figure 7 shows the changes in connectivity, before (A) and after (B) construction of the railway. Thereby, the width of the links has been scaled proportionally to the encountered resistance. Thereby, the scaling is relative to the resistance surface. Because the overall resistance is much larger when the railway is included both figures are not directly comparable. However, they clearly indicate the overall shift in connectivity between nodes.

There are three key observations to be made regarding network disruption. The southern section of the railway ranging from Grenctāle to Sarmas, located before the railway divides into the Riga mainline and bypass, crosses an area with lower overall connectivity. The relatively small hub size and poorer connectivity within the vicinity of this section renders it particularly vulnerable to any disruption in potential movement corridors and thus it is important to maintain permeable features within this part of the railway to allow for species movement between patches and patch networks located east and west of the railway. While due to the lower patch density a lower amount of animal movement can be assumed it is essential not to further degrade regions that feature lower connectivity.

The second potential disruption risk is the area where the railway splits to form a bypass around Riga (full extent of railway not shown) which incircles several patches. Although these patches are located in peri-urban areas and their overall size is small, they are at a high risk of isolation. Furthermore, they present steppingstones for the adjacent larger patches located east of Jurmala.

The third key observation relates to the circumstance that larger patches are only affected directly, within the area North East of Riga where the railway could potentially segregate two larger hub agglomerations. Due to the circumstance that the Northern Vidzeme Biosphere Reserve is considered a single hub the potential disruption between smaller natural areas within the reserve cannot be seen on the map.

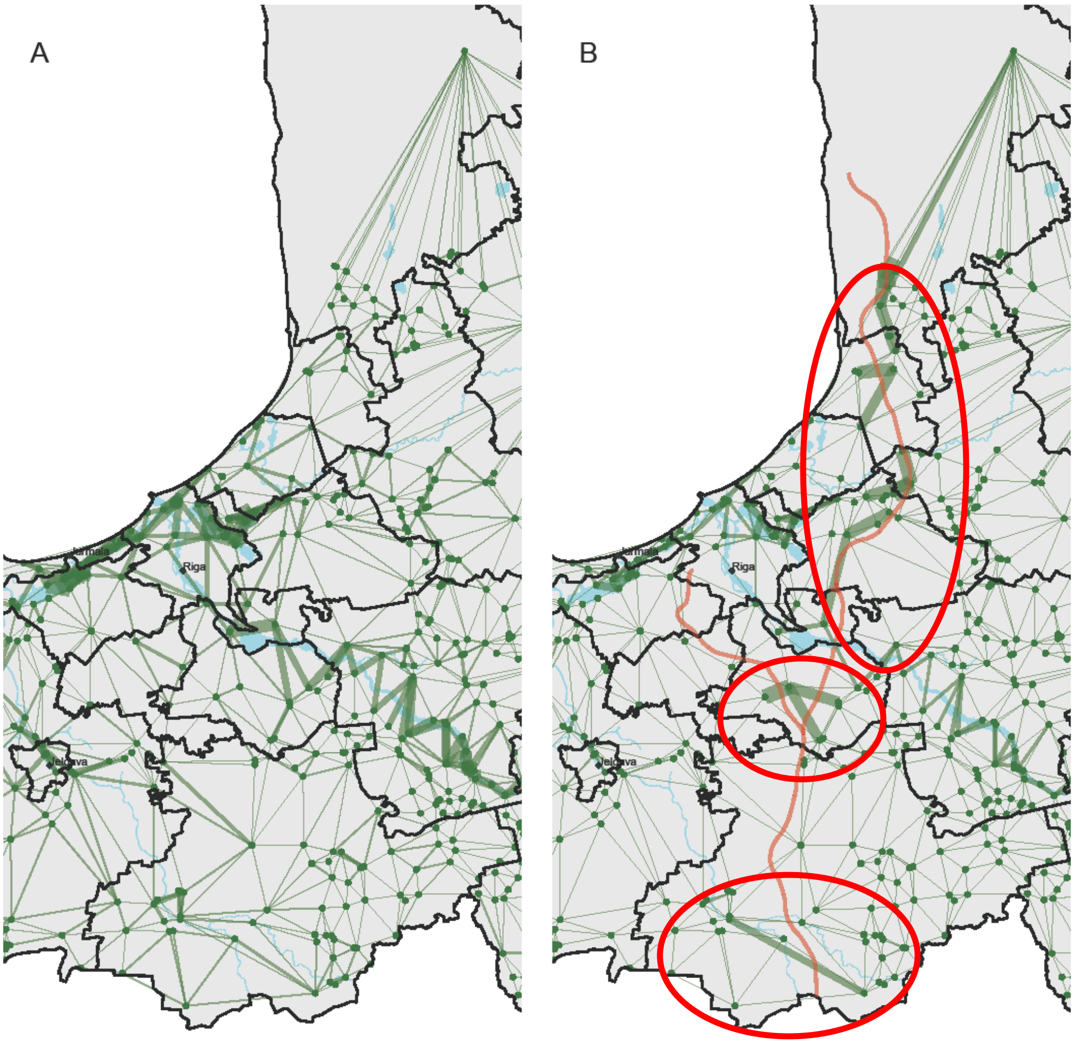


Figure 7 shows the changes in connectivity, before (A) and after (B) construction of the railway. Both, A) and B) show a minimum planar graph (MPG) with centroid node and link representation where the width of the links has been scaled proportionally to the encountered landscape resistance. Wider links therefore correspond to reduced connectivity. B) Indicates the network disruption by the construction of the Rail Baltica. There are notable increases in resistance observed South and northeast of Riga as well as in the Southernmost area (red ellipse).

4.2 Ecosystem services

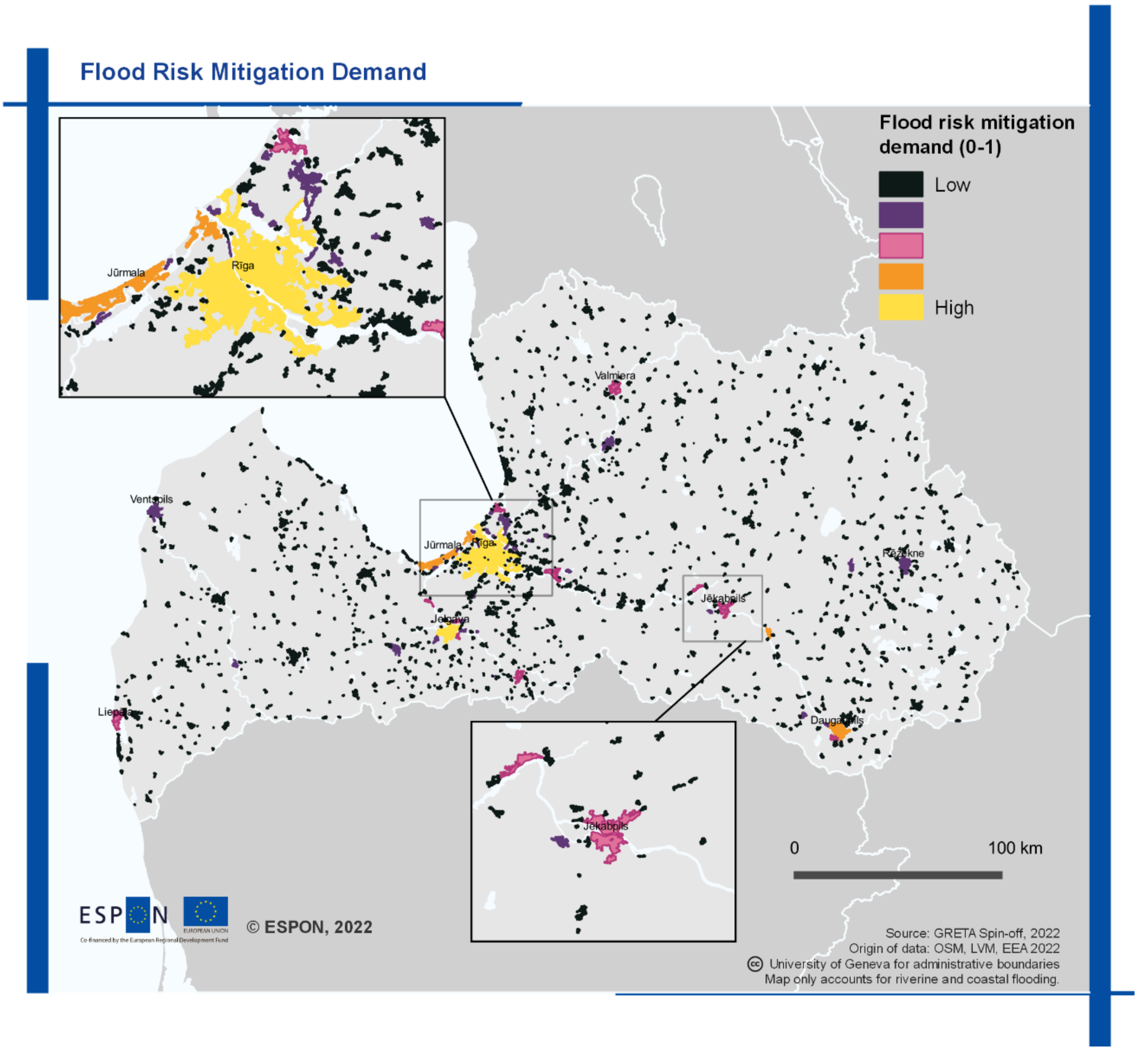
All ecosystem services have been mapped at national level. Depending on the service the coverage is either wall-to-wall or localized at polygon level. The units of the services are context dependent and are rather treated as relative dimensionless values rather than specific physical units. Data classification is thereby often based on a 5-class Jenks value classification, that allows to discern very low – very high values in different regions.

4.2.1 Flood risk mitigation

4.2.1.1 Demand

The demand for flood risk mitigation (Map 4) is the highest in population centres that feature a high population density coinciding with a high flood risk (Not shown). Frequently these cities are located in coastal areas at the mouths of major rivers (e.g. Riga, Jurmala), which historically allowed to sustain a larger population. This geographically favourable location has the disadvantage of rendering them prone to a dual threat by both coastal and riverine flooding.

Areas that are not affected by riverine or coastal flooding feature the lowest value i.e., there is no demand. These urban conglomerations are also mostly located in more rural areas with lower population density. Due to input data restriction the mapping approach could not account for flash floods which may pose a serious hazard during extreme precipitation events.

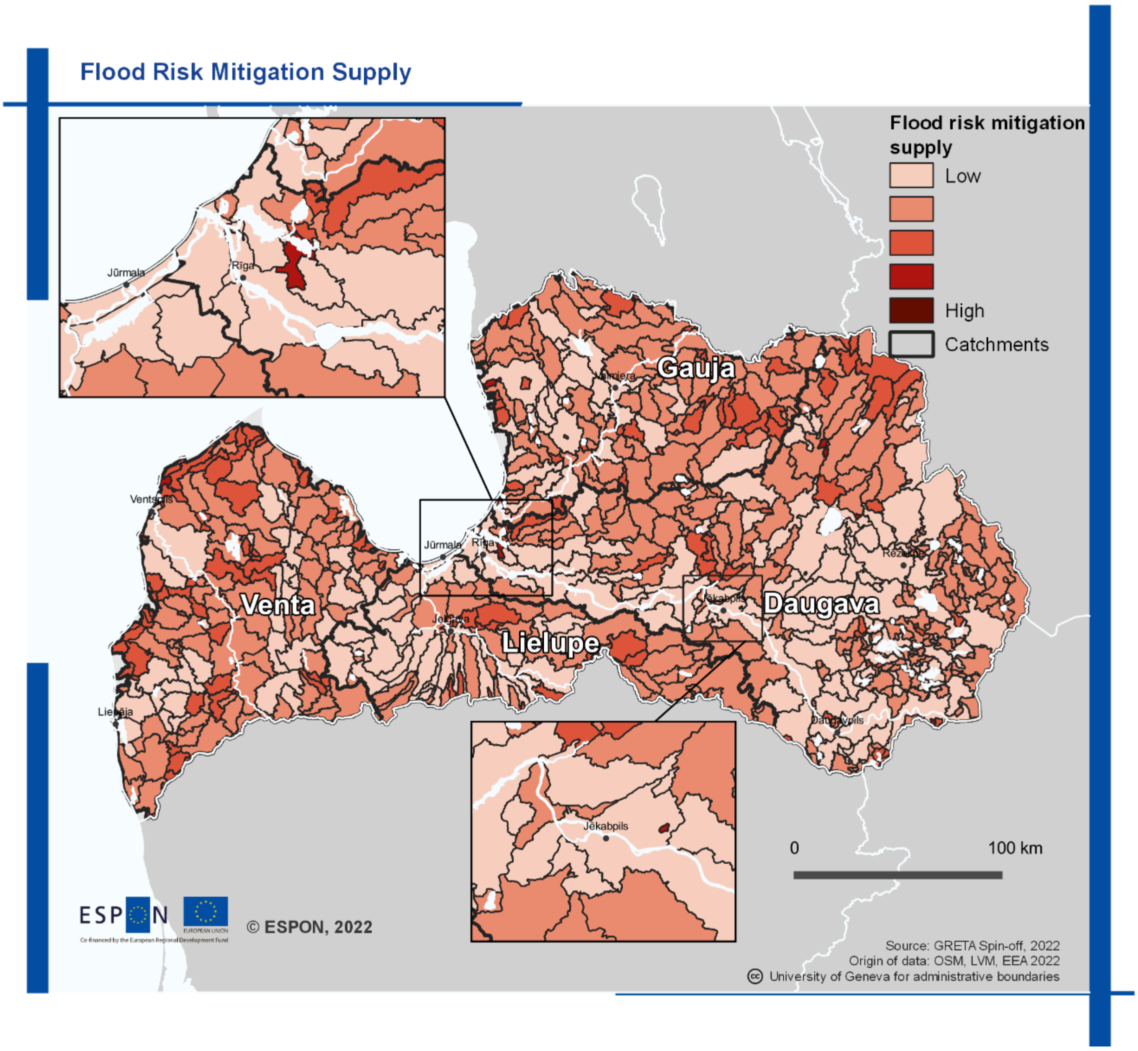


Map 4 Flood risk mitigation demand mapped on the basis of population density and riverine as well as coastal flooding intensity.

4.2.1.2 Supply

Flood risk mitigation supply was mapped by weighting the proportion of natural and semi-natural area within a catchment by their water retention capability (Map 5). Thus, areas with dense urban fabric generally feature a low supply as they feature a high proportion of artificial impervious land cover.

There is large inter-catchment variability to be observed across Latvia. There is a notable occurrence of low supply sub-catchments along the entire course of the Daugava River, which is likely related to the higher concentration of agricultural area within the greater catchment. This also translates to other agriculture dominated areas within the Zemgale plain, Kurzeme and Vidzeme areas. Both the Gauja and Venta catchments feature a higher proportion of water retention supply in headwater areas.



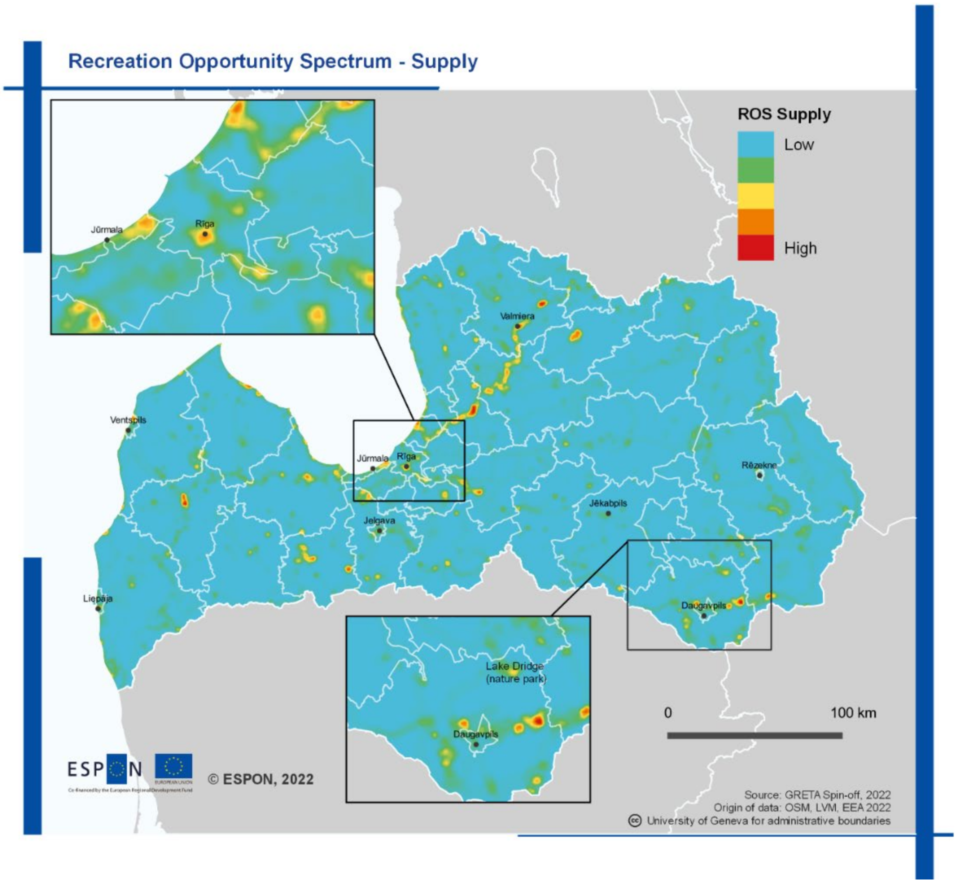
Map 5 Flood risk mitigation supply mapped on the basis of the proportion of (semi-)natural classes identified from the national topographic map weighted by their respective water retention capability. The later was based on expert opinion and ranges from 1 (low) to 3 (high). Results are aggregated on the basis of national catchments.

4.2.2 Recreation opportunity spectrum

4.2.2.1 Supply

Most regions within Latvia feature at least one recreation opportunity within immediate walking distance (Map 6). Supply peaks are found in areas where many opportunities occur in close proximity. This can include areas where e.g. lakes are used for swimming and fishing and hiking and biking paths can be found nearby. Hot spots were frequently observed in the vicinity of cities that feature larger patches of woodlands or lakes in in their immediate surroundings. Examples are Valmiera, Sigulda as well as Kuldīga. Low supply is predominantly found in more rural and/or agriculture dominated areas. In addition, there appears to be only few touristic options along the terrestrial borders, especially facing Russia.

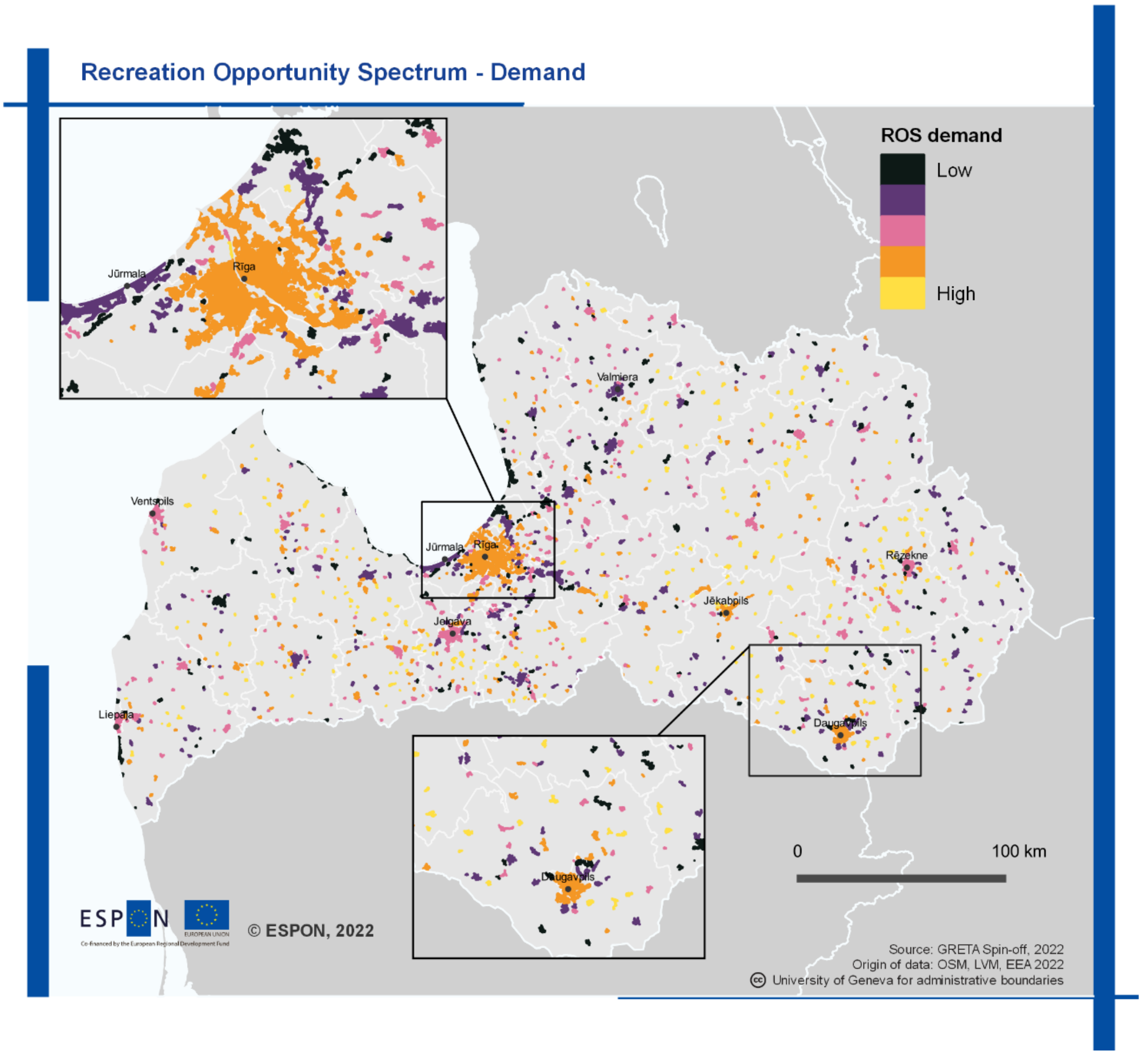
> What is considered a recreational opportunity?
>
> Outdoor recreation can consider a fast range of activities. They can be different in their degree of physical requirements, such as going for multi-day hike or taking a stroll into the next park. The recreational opportunities covered in the map mainly include activities that require a minimum of physical involvement. Lakes and rivers are scenic attractions and elements of Blue Infrastructure. Here they are only considered for their direct use as platform for physical activity. Meaning that either mapped as recreation opportunity if swimming or fishing activities have been confirmed for the given waterbody.
>
> This is not the case for the coastline where the frequent occurrence of bathing spots as well as hiking paths translates into a higher ROS supply.



Map 6 Density of recreation opportunities within a 1500m radius, based on hiking, biking, swimming, fishing, viewpoints and picnic site data and recreational forests across the country.

4.2.2.2 Demand

ROS demand is derived from intersecting ROS supply with population density to calculate ROS supply on a per capita basis (Map 7). Areas with especially high demand can be found within densely populated cities due to lower relative supply per capita but also in rural communities, where recreation opportunities may be absent.



Map 7 ROS demand based on ROS supply and population density.

4.3 GI accessibility assessment

Figure 8 shows the mean density of ROS supply within isochrones of different time intervals around the nine urban cores for travel by car.

Except for the capital Riga, most cities show the highest availability of recreational opportunities within 10 min car travel. This mirrors the findings that rural areas appeared to have fewer opportunities regardless of their more natural surroundings.

ROS supply generally decreases incrementally with increasing travel time. Daugavpils, Ventspils and Riga feature among the lowest availability of ROS supply. The highest density of recreational opportunities was found in Rezekne, which is located in close proximity to a national park.

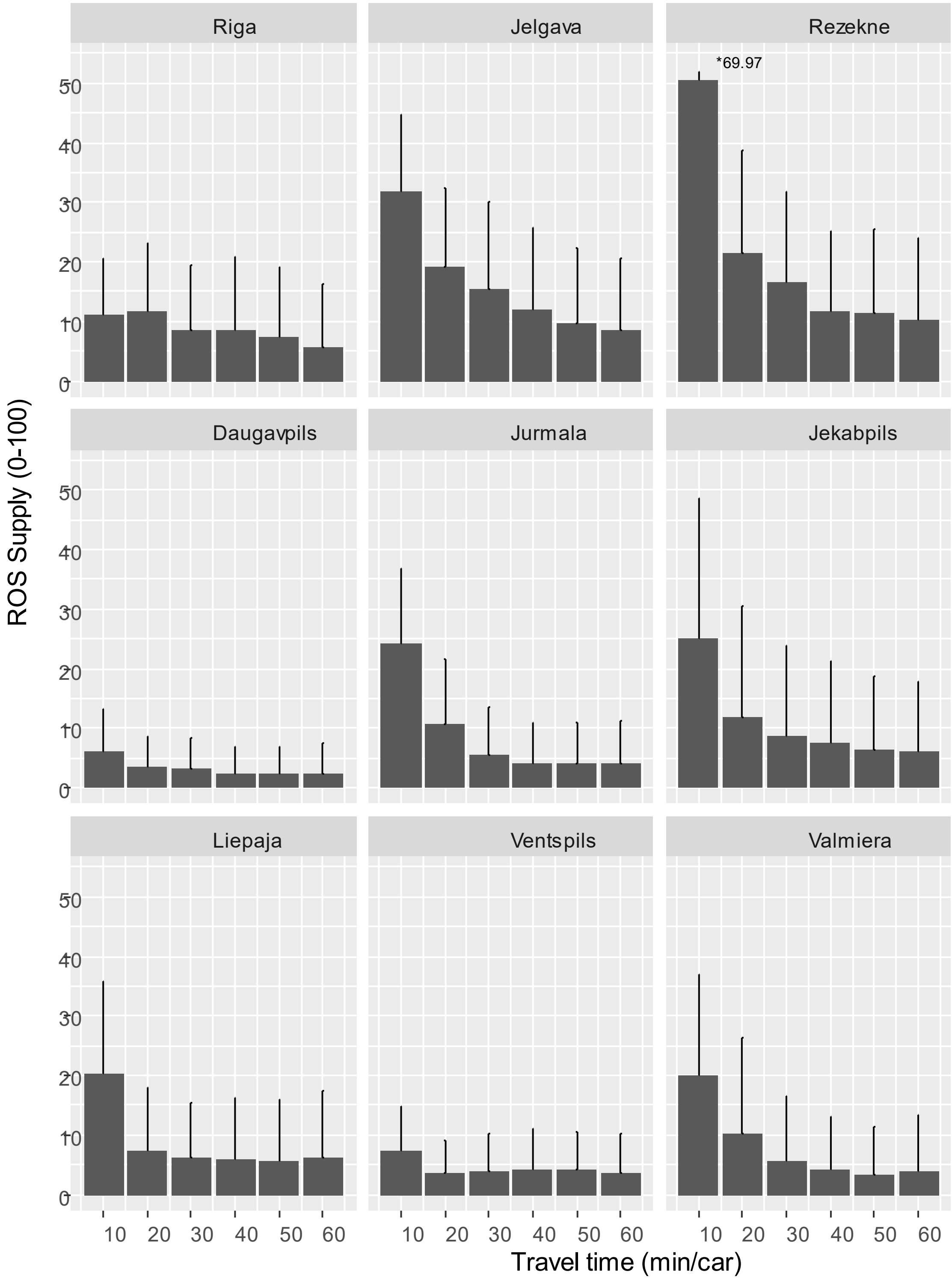


Figure 8 Barplot of ROS density by car travel distance isochrones located around city centres.

Figure 9 shows recreation density within different walking distances from the city centre. The highest values were mostly observed within 10 minutes walking distance. Jekabpils and Rezekne featured the highest density in close proximity to the city centre, while the lowest densities were observed in Ventspils and Daugavpils. Jelgava was the only city to show increasing ROS supply with increasing distance. Ventspils featured the lowest total decrease by distance. Similar to the (larger) travel distances by car mid-range values were observed for Riga.

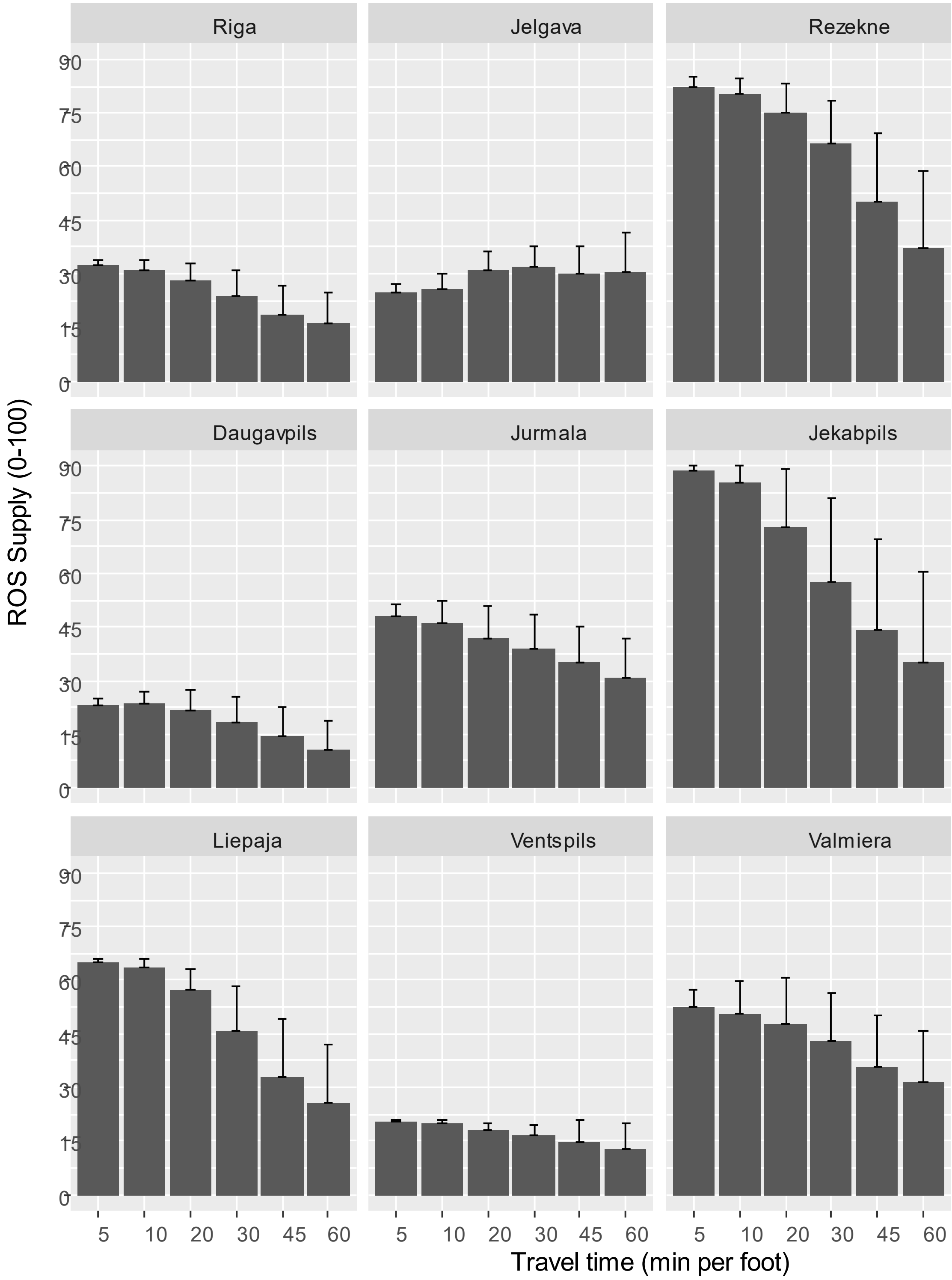


Figure 9 Barplot of ROS density by walking distance isochrones outward from city centres.

5 Key findings

GI physical network

- Areas considered as Green Infrastructure hubs amount to approximately ~20% of Latvia´s terrestrial territory. These areas fall under different legislative protection status and vary extremely in size and landscape composition.
- Hubs appear to be predominantly well connected by links (i.e. potential distance-based movement corridors). This can be attributed to the high frequency of small, interspersed hubs allowing for improved movement opportunities and “island hopping”.
- There are only a few hubs that are more likely prone to isolation. These are situated in urban conglomerations. An evaluation on how to improve their situation likely requires a tailored approach which parametrizes the links by the movement capacity of species that shall be supported.

GI network disruption risks

- In total, the railway interrupts potential links at 52 different locations. This translates into an average link interruption for every 11km of railway section. More than 120 different hubs are potentially affected by the network disruption due to interruption of links amounting to almost 40% of the total hub area due to its proximity to very large hubs.
- The southern section of the railway ranging from Grenctāle to Sarmas, located before the railway divides into the Riga mainline and bypass, crosses an area with lower overall connectivity. While due to the lower patch density a lower amount of animal movement can be assumed, it is essential not to further degrade regions that already poorly connected.
- The split of the mainline and bypass causes a drastic decrease in connectivity in the direct vicinity of the split by essentially creating two barrier lines and encircling a large area around Riga.
- Northeast of Riga the railway could potentially segregate two larger hub agglomerations thereby separating coastal from inland area.

ES flood risk mitigation

- The highest demand for flood protection was determined for Riga which, like many coastal cities, features a geographically unfavorable situation being prone to both, riverine and coastal flooding. In general, flood mitigation demand was mostly proportional to population density. This can be explained by the circumstance that locations along major streams were historically more likely to be able to sustain a larger population and thus higher population density can be found along larger rivers. Simultaneously, these rivers are more prone to flooding as discharge may accumulate across the sub-catchments of the watershed. Flash floods were not considered as flood hazard due to missing data. Considering that extreme precipitation events are likely to increase with the intensification of climate change it may be important to incorporate such data.
- The large number of wetlands and forests present in the country contribute towards the water retention capacity of the landscape. Most of the four major river systems featured a medium to high water retention capacity. The lowest values for water retention capacity were observed in the Daugava river catchment. The methodological approach towards assessing water retention capacity remains simplistic and could not consider import aspects such as soil type and hydrology as well as the impacts of different discharge volumes.

ES Recreation opportunity spectrum

- Latvia features a large range of outdoor activities considered under the recreation spectrum. The mapping approach showed that there are generally fewer immediate opportunities available to the rural population in comparison to the population of larger and medium sized cities. Thereby, the peaks of available activities are not located within the cities, but in their immediate surroundings. These surroundings are also frequently protected hubs.
- Although the rural population may have more direct access to natural areas, these are generally less developed in terms of available (and integrated) recreation opportunities. However, this does not mean that rural population is per se deprived of these opportunities. For example, despite the large abundance of natural lakes that are suitable for bathing around the country, the ROS supply only considers official bathing waters. The estimation of bathing water is thus kept conservative but is likely to underestimate the true amount of available swimming and bathing locations. This trade-off situation between overestimation (simply considering all natural lakes as bathing water) and underestimation is a frequent problem in the design of ES and may be optimized by integrating an additional weighting mechanism. Like bathing, other recreational activities that occur more decentralized and disperse such as e.g. mushroom picking are difficult to capture without suitable data and are thus not accounted for.

GI accessibility assessment

- The accessibility assessment showed that the largest population centre in Latvia, Riga, only provides medium recreation opportunities in comparison to the remaining 8 larger urban centres. With the exception of Jelgava, there was an evident decrease of ROS towards the outer perimeter of the considered travel times.

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7 Annexes

Table 2 Resistance values for topographic map used to map GI links between hubs.

FNAME	NAME_EN	RES
poligons_Augļudārzs	Orchard	70
poligons_Kapi	Cemetery	80
poligons_Krūmājs	Shrubs	3
Sēklis_poligons	Sand bank	70
poligons_Sakņudārzs	Allotment garden	80
poligons_Smiltājs	bare soil / heath	3
poligons_Mezs	Forest	2
poligons_Krūmaugu_plant	Shrub plant	3
poligons_Nec_purvs_sūnājs	Mossy swamp	6
poligons_Sūnājs	Moss and Lichens	4
poligons_Grīslājs	Area covered by Carex plants (grīslis)	6
poligons_Nec_purvs_meldrājs	Swamp with Scirpus plant	6
poligons_Pārējās_zemes	Agricultural land	6
poligons_Skrajmezs	Sparse forest	2
poligons_Meldrājs	Area covered by Scirpus plant	5
poligons_Parks	Park	80
poligons_Grants	gravel	5
poligons_Kūdra	Peatland	70
poligons_Zāliens	Lawn/grass	70
poligons_Meza_kapi	Forest cemetary	3
poligons_Izcirtums	Forest clearing	2
poligons_Ogulājs	Area of berry plants	70
poligons_Pārējās_zemes	Transitional land	70
poligons_Zālaugu_plant	Herbaceous plants	4
poligons_Jaunaudze	Area of new forest growth	2
poligons_Nec_purvs_grīslājs	Swamp with Carex plant	6
Meldrājs_ūdenī_poligons	Area where Carex grows in water	6
poligons_Izdegums	Burnt-out area	5
poligons_Pļava	wet meadow	4
Caurejams_purvs_poligons	Swamp	6
poligons_Ūdens	Water	1000
poligons_Vasarnīcu_apbūve	Building (Holiday house)	1000
poligons_Blīva_apbūve	Building (Dense)	1000
poligons_Viensētu_apbūve	Isolated structures	70
poligons_Ceļš_grants_segums	Non-sealed road	70
poligons_Brauktuve	Secondary road	70
poligons_Ceļš_ciets_segums	Primary road	1000
Lidosta lidlauks	Airport	1000
Dzīvojamā vai saimn ēka mērogā	Residential & Commercial buildings	1000

Nojume paviljons lapene mērogā	Pavilion	1000
Drupas mērogā	Ruins	1000
Stadions	Stadion	1000
Siltumnīca mērogā	Green house	1000
Pagrabs mērogā	Subterrain Parking	1000
Jaunbūve mērogā	Construction	1000
Ierīkota piestātne mērogā	Pier	1000
Platforma mērogā	Train platform	1000
Transformators	Power converter	1000
Tornis mērogā	Tower	1000
Lokomotīvju apgriešanās aplis	Train station turning platform	1000

FNAME	NAME_EN	Permeability	Naturalness	Flood mitigation potential
poligons_Augļudārzs	Orchard	High	Agricultural	High
poligons_Kapi	Cemetery	High	Artificial	Medium
poligons_Krūmājs	Shrubs	High	Natural	High
Sēklis_poligons	Sand bank	High	Natural	Low
poligons_Sakņudārzs	Allotment garden	High	Agricultural	Medium
poligons_Smiltājs	bare soil / heath	High	Natural	Low
poligons_Mezs	Forest	High	Natural	High
poligons_Krūmaugu_plant	Shrub plant	High	Natural	High
poligons_Nec_purvs_sūnājs	Mossy swamp	High	Natural	High
poligons_Sūnājs	Moss and Lichens	High	Natural	High
poligons_Grīslājs	Area covered by Carex plants (grīslis)	High	Natural	High
poligons_Nec_purvs_meldrājs	Swamp with Scirpus plant	High	Natural	High
poligons_Pārējās_zemes	Agricultural land	High	Agricultural	Medium
poligons_Skrajmezs	Sparse forest	High	Natural	High
poligons_Meldrājs	Area covered by Scirpus plant	High	Natural	Medium
poligons_Parks	Park	High	Artificial	Medium
poligons_Grants	gravel	High	Natural	Low
poligons_Kūdra	Peatland	High	Natural	High
poligons_Zāliens	Lawn/grass	High	Artificial	Medium
poligons_Meza_kapi	Forest cemetary	High	Artificial	High
poligons_Izcirtums	Forest clearing	High	Natural	Low
poligons_Ogulājs	Area of berry plants	High	Agricultural	Medium
poligons_Pārējās_zemes	Transitional land	High	Natural	Low
poligons_Zāļaugu_plant	Herbaceous plants	High	Natural	Medium
poligons_Jaunaudze	Area of new forest growth	High	Natural	High
poligons_Nec_purvs_grīslājs	Swamp with Carex plant	High	Natural	High
Meldrājs_ūdenī_poligons	Area where Carex grows in water	High	Natural	High

poligons_Izdegums	Burnt-out area	High	Natural	Low
poligons_Pļava	wet meadow	High	Natural	High
Caurejams_purvs_poligons	Swamp	High	Natural	High
poligons_Ūdens	Water			
poligons_Vasarnīcu_apbūve	Building (Holiday house)	Low	Artificial	Low
poligons_Blīva_apbūve	Building (Dense)	Low	Artificial	Low
poligons_Viensētu_apbūve	Isolated structures	Low	Artificial	Low
poligons_Ceļš_grants_segums	Non-sealed road	Medium	Artificial	Low
poligons_Brauktuve	Secondary road	Low	Artificial	Low
poligons_Ceļš_ciets_segums	Primary road	Low	Artificial	Low
Lidosta lidlauks	Airport	Medium	Artificial	Low
Dzīvojamā vai saimn ēka mērogā	Residential & Commercial buildings	Low	Artificial	Low
Nojume paviljons lapene mērogā	Pavilion	Low	Artificial	Low
Drupas mērogā	Ruins	Low	Artificial	Low
Stadions	Stadion	Low	Artificial	Low
Siltumnīca mērogā	Green house	Low	Agricultural	Low
Pagrabs mērogā	Subterrain Parking	Low	Artificial	Low
Jaunbūve mērogā	Construction	Low	Artificial	Low
Ierīkota piestātne mērogā	Pier	Low	Artificial	Low
Platforma mērogā	Train platform	Low	Artificial	Low
Transformators	Power converter	Low	Artificial	Low
Tornis mērogā	Tower	Low	Artificial	Low
Lokomotīvju apgriešanās aplis	Train station turning platform	Low	Artificial	Low

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ESPON 2020

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